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A LIMITED EVALUATION OF THE HAVE DERIVATIVES PROCESS TO REDUCE AIRCRAFT STABILITY DERIVATIVE ESTIMATE ERRORS CAUSED BY TURBULENCE (HAVE DERIVATIVES)

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FINAL REPORT

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EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE MATERIEL COMMAND
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This report presents the results of a limited evaluation of the HAVE DERIVATIVES data reduction process in reducing aircraft stability derivative estimate errors caused by turbulence. The evaluation consisted of 11 sorties totaling 15.2 flight hours. The sorties were flown at the Air Force Flight Test Center, Edwards AFB, California, in a production-representative Block 15 F-16B aircraft. The three specific objectives for this project were to establish a basis data set of results against which to compare the results of the subsequent tests; compare stability derivative estimate results found using the HAVE DERIVATIVES process with Personal Computer Parameter Identification (PCPID), on calm air data, to the basis data set results established in objective 1; and compare stability derivative estimate results found using PCPID alone and the HAVE DERIVATIVES process with PCPID, on turbulent air data, to the basis data set results established in objective 1, and to each other.

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PREFACE

This report presents the results of a limited evaluation of the HAVE DERIVATIVES data reduction process in reducing aircraft stability derivative estimate errors caused by turbulence. This evaluation was conducted in support of an Air Force Institute of Technology (AFIT) Masters degree thesis. The test program was requested and funded by the Air Force Institute of Technology, Wright-Patterson AFB, Ohio, and was directed by the Commandant, USAF Test Pilot School, under Job Order Number M96J0200.

Captain Hoffman is grateful to his AFIT thesis advisor, Dr. Brad Leibst, for his frequent help in developing and analytically testing the HAVE DERIVATIVES process. Special thanks are given to Messrs. Chris Nagy and Ralph Smith for their generous assistance during postflight data analysis. Their insights and experience into aircraft stability derivative estimation and frequency response analysis were instrumental to the success achieved by this project. Thanks also to Messrs. Joe Barnicki and Pat Mattingly of Quartic Engineering for their help in developing interface patches between the Personal Computer Parameter Identification software package and external computer programs.

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EXECUTIVE SUMMARY

This report presents the results of a limited evaluation of the HAVE DERIVATIVES data reduction process in reducing aircraft stability derivative estimate errors caused by turbulence. The evaluation consisted of 11 sorties totaling 15.2 flight hours in a production-representative Block 15 F-16B aircraft. The sorties were flown at the Air Force Flight Test Center, Edwards AFB, California, from 15 September to 7 October 1997.

The test item was the HAVE DERIVATIVES data reduction process in which aircraft time responses to pitch sweeps were transformed into the frequency domain using fast Fourier transforms. Random variations caused by turbulence were then minimized through an ensemble averaging technique. The averaged frequency responses were transformed back into the time domain as discrete pulse responses using inverse fast Fourier transforms (IFFTs). Those responses and a computer generated discrete pulse input were then entered into the Personal Computer Parameter Identification (PCPID) program, which is the parameter estimation software currently used by the USAF Test Pilot School. Comparison stability derivative estimate results were generated by using aircraft time responses to pitch doublets in the PCPID with no additional processing.

The specific test objectives were:

1. establish a basis data set of results against which to compare the results of the subsequent tests,

2. compare stability derivative estimate results found using the HAVE DERIVATIVES process with PCPID, on calm air data, to the basis data set results established in objective 1, and

3. compare stability derivative estimate results found using PCPID alone and the HAVE DERIVATIVES process with PCPID, on turbulent air data, to the basis data set results established in objective 1, and to each other.

All test objectives were met. The basis data set was established using the currently accepted method of estimating stability derivatives in which aircraft response data gathered in calm air were entered directly into PCPID. The test team concluded that sufficient statistical evidence was available to conclude the estimated stability derivatives calculated for the basis data set were accurate. The F-16B simulation responses in calm air conditions were modified using the HAVE DERIVATIVES data reduction process. Entering these modified response data into PCPID initially resulted in poor stability derivative estimates. This was due to the positive value of $C_{m\alpha}$, used in the F-16B aircraft model, which resulted in unstable responses that PCPID could not match. This positive value of $C_{m\alpha}$ was taken from the basis data set and clearly showed the marginally stable nature of the F-16B aircraft. The $C_{m\alpha}$ was changed to a very small negative value, stable, and resulted in stability derivative estimates very similar to the actual stability derivative values. Unfortunately, such similarities were not noted when actual flight data gathered in calm air were reduced using the HAVE DERIVATIVES data reduction process and PCPID. This difference was concluded to be the result of different inputs being given to the F-16B simulation, a broadband input, versus the actual F-16B aircraft employed during flight test which used a frequency sweep as the input. Poor stability derivative estimates were also noted when turbulent air data were reduced using the HAVE DERIVATIVES data reduction process along with PCPID for the same reason. In order to improve the stability derivative estimates, aircraft response data, gathered both in calm and turbulent air, were filtered using a low-pass Butterworth filter. These filtered data were then reduced using the HAVE DERIVATIVES data reduction process and entered into PCPID. At the same time, the computer-generated discrete pulse input also entered into the PCPID was filtered using the same low-pass Butterworth filter. The resulting stability derivative estimates were significantly more accurate than the stability derivatives estimated using nonfiltered data and, in general, closely matched the basis data set.

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INTRODUCTION

GENERAL

This report presents the results of a limited evaluation of the HAVE DERIVATIVES data reduction process in reducing aircraft stability derivative estimate errors caused by turbulence. The evaluation was conducted in support of an Air Force Institute of Technology (AFIT) Masters degree thesis to be completed in February 1998 by Captain Lawrence M. Hoffman. Testing was conducted by the USAF Test Pilot School (TPS), Edwards AFB, California, the responsible test organization. Eleven sorties totaling 15.2 flight hours were flown from 15 September to 7 October 1997. Data from only 9 of the 11 sorties were used in the evaluation; flight 7 was terminated early due to a bird strike and the data acquisition system (DAS) tape recorded during flight 11 was corrupt. All test flights flown in support of project HAVE DERIVATIVES were launched from and recovered at Edwards AFB. Test flights were flown in the R-2508 complex.

BACKGROUND

Development of the HAVE DERIVATIVES process began in April 1996 at the AFIT. Between April and December 1996, multiple computer simulations using an AT-37B aircraft model were conducted. Those simulations analytically demonstrated that the process was effective at reducing stability derivative estimate errors caused by turbulence. The simulations also showed that the HAVE DERIVATIVES process gave better stability derivative estimate results even when turbulence was not present. Further simulations were conducted at the USAF TPS using an F-16B aircraft model based on stability derivative estimates generated during USAF TPS model validation curriculum sorties, flown in May 1997, in a Block 15 F-16B aircraft, USAF S/N 80-0635, the same aircraft used for the HAVE DERIVATIVES project. Preliminary analysis of the HAVE DERIVATIVES process using actual aircraft response data from the same model validation missions was conducted between May and September 1997. Those efforts culminated in the flight tests conducted and are discussed in this report.

The current computer program used for estimating aircraft stability derivatives at the USAF TPS, Personal Computer Parameter Identification (PCPID), requires good correlation between the commanded input, typically a doublet, and the aircraft's response to that input. Variance in the aircraft's response due to extraneous and undesired inputs, such as turbulence, resulted in less than accurate stability derivative estimates. These estimates are the result of the inability of the PCPID to discern the response of the aircraft due to the commanded input from the response of the aircraft, due to turbulence. To minimize the degrading effects of turbulence, the aircraft must be flown through calm air. The HAVE DERIVATIVES data reduction process was designed to minimize the variance in stability derivative estimates due to air turbulence, and as a result, allow data collected during test flights flown in less than ideal calm conditions to be used for stability derivative estimation.

This limited evaluation compared the stability derivative estimates of $C_{N\alpha}$, $C_{N\delta e}$, $C_{m\alpha}$, C_{mq}, and $C_{m\delta e}$ calculated using both PCPID alone and the HAVE DERIVATIVES process with PCPID from aircraft response data gathered in both calm and turbulent air. Additional measures of the accuracy and precision of the estimates were also used in the limited evaluation.

TEST ITEM DESCRIPTION

The test item was the HAVE DERIVATIVES data reduction process. The process was a method by which aircraft time responses to a pitch sweep were first measured and then transformed into the frequency domain via a fast Fourier transform (FFT). Once in the frequency domain, an ensemble averaging process was applied to these data which minimized signal variance due to noise. The focus of this project was to reduce the variance (noise) caused by turbulence. An inverse fast Fourier transform (IFFT) was then operated on the averaged frequency responses to transform them back into the time domain where they became the aircraft's discrete pulse responses. The responses, along with a computer generated discrete pulse input, were entered into the PCPID which estimated the aircraft's stability derivatives of interest (Appendix F). The PCPID User's Manual describes the program and its implementation in detail (Reference 1).

TEST AIRCRAFT

A Block 15 F-16B aircraft, USAF S/N 80-0635, was chosen as the test aircraft based on instrumentation fidelity and aircraft availability. The

test aircraft incorporated several modifications from the standard Block 15 F-16B configuration. External modifications were a yaw angle-of-attack Pitot-static (YAPS) flight test noseboom mounted to the F-16B radome, and an additional total temperature probe mounted at approximately the wing root, leading edge intersection. Cockpit modifications were a sensitive airspeed indicator mounted in place of the production airspeed indicator and a modified altimeter, adjusted and calibrated for better accuracy, mounted in place of the production altimeter. Flight test maneuvers were conducted with reference to the front cockpit instruments. Finally, an airborne test instrumentation system (ATIS) DAS was installed on the aircraft (Reference 2). A complete description of all modifications to the test aircraft can be found in the F-16A/B Modification Flight Manual (Reference 3).

External modifications to the aircraft were designed to minimize aerodynamic interference with the aircraft. None of the modifications affected the thrust producing capability of the aircraft. Although the weight of the aircraft was increased by the additional instrumentation, this increase was not significant relative to the gross weight of the aircraft. Following the modifications, the center of gravity was checked to ensure it was within limits. Since neither the aerodynamics, thrust producing capability, weight, or center of gravity were significantly altered by the aircraft modifications, the test aircraft was considered production representative.

TEST OBJECTIVES

The overall test objective of this project was to perform a limited evaluation of the HAVE DERIVATIVES process to reduce stability derivative estimate errors caused by turbulence.

This overall objective was further defined by the following three specific test objectives:

1. Establish a basis data set of results against which to compare the results of the subsequent tests;

2. Compare stability derivative estimate results found using the HAVE DERIVATIVES process with PCPID, on calm air data, to the basis data set results established in objective 1; and

3. Compare stability derivative estimate results found using PCPID alone and the HAVE DERIVATIVES process with PCPID, on turbulent air data, to the basis data set results established in objective 1, and to each other.

All test objectives were met.

TEST AND EVALUATION

GENERAL

This report presents the results of a limited evaluation of the HAVE DERIVATIVES data reduction process in reducing aircraft stability derivative estimate errors caused by turbulence. The evaluation was conducted in support of an AFIT Masters degree thesis completed in February 1998 by Captain Lawrence M. Hoffman. Testing was conducted by the USAF TPS, Edwards AFB, California, the responsible test organization. Eleven sorties totaling 15.2 flight hours were flown between 15 September and 7 October 1997. Data from only 9 of the 11 sorties were used in the evaluation; flight 7 was terminated early due to a bird strike and the DAS tape recorded during flight 11 was corrupt. All test flights flown in support of project HAVE DERIVATIVES were launched from and recovered at Edwards AFB. Test flights were flown in the R-2508 complex.

TEST PROCEDURES

Flight Test:

All test flights were flown with the F-16B aircraft configurations as presented in Table 1. The location of each test flight within the R-2508 complex was chosen by the aircrew based primarily on the level of turbulence desired for a particular flight. Every attempt was made to remain as close as possible to Edwards AFB to allow constant telemetry reception from the test aircraft.

Each test flight consisted of approximately 15 passes. A pass was defined as a 10-second trim shot followed by a series of 3 pitch doublets, followed by a second 10-second trim shot, followed by a pitch sweep of approximately 60 seconds in duration.

The trim shots were accomplished to assess the level of turbulence prior to a particular pass. Table 2 presents turbulence level definitions used during testing.[1] The conditions were defined based on the average normal acceleration deviations at the test aircraft short period undamped natural frequency, approximately 1 radian per second.

Table 1
TEST AIRCRAFT CONFIGURATION

Component	Cruise Configuration
Landing Gear	RETRACTED
Leading Edge Flaps	AUTO
Alternate Flaps	NORM
Speedbrakes	CLOSED
Altimeter	29.92-in Hg (PNEU)
Engine Air Source	NORM
Air Conditioning	AUTO
EEC/BUC	EEC
Probe Heat	ON
Anti-Ice	AUTO
Category Switch	I
Center-of-Gravity Range	35.88- 37.38-pct MAC
Station	**Store**
1 and 9 (Wingtips)	16S210 Missile Rails
5 (Centerline)	300-gallon fuel tank

Notes: 1. AUTO – automatic
2. NORM - normal
3. Hg – Mercury
4. PNEU - pneumatic
5. EEC - electronic engine control
6. BUC - backup control
7. MAC - mean aerodynamic chord

[1] Throughout this report, turbulence refers only to vertical disturbances, which had the primary influence on the longitudinal stability derivative results.

Table 2
TURBULENCE DEFINITIONS

Turbulence Level	ΔNormal Acceleration (Δg)[1]
Calm Air	$\lvert \Delta n_z \rvert \leq 0.1$
Turbulent Air	$0.3 \leq \lvert \Delta n_z \rvert$

Notes: 1. Δ - increment of change
2. g - acceleration due to gravity
3. n_z - normal acceleration

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

The change in normal acceleration at the test short period undamped natural frequency of the aircraft was used as the measure of turbulence since it was reasoned that turbulence at that frequency would have the greatest impact on the aircraft's longitudinal response and, consequently, on the stability derivative estimates for $C_{N\alpha}$, $C_{N\delta e}$, $C_{m\alpha}$, C_{mq}, and $C_{m\delta e}$.

The pitch doublets were accomplished to gather aircraft response data necessary to estimate stability derivatives using PCPID alone. Pitch sweeps were accomplished to gather aircraft response data necessary to estimate stability derivatives using the HAVE DERIVATIVES process with PCPID. A more detailed description of the maneuvers performed during each pass is presented in Appendix D.

During each pass, the parameters specified in Appendix E were recorded by the ATIS DAS on board the F-16B aircraft. Passes one through four of the first test flight were flown at 8,000 feet pressure altitude (PA) and 0.60 Mach number (M) for the purpose of verifying that the test instrumentation and data reduction processes were operating properly. The stability derivatives estimated from those four passes were compared to stability derivatives estimated at the same flight condition as presented in the Air Force Flight Test Center (AFFTC) technical letter report (TLR), AFFTC-TLR-92-12, *F-16B Parameter Estimation (PEST)* (Reference 4).

The remaining four passes from the first flight, along with all other test flights, were flown at 4,000 feet PA and 0.65 M. This test condition was chosen based on a tradeoff between the desire to fly as low to the ground as possible to encounter turbulence, and the safety concerns associated with low-altitude flight. Flying at 4,000 feet PA provided at least 1,000 feet AGL clearance along all routes flown during the test. This flight condition represented a 'heart of the envelope' point for the F-16B aircraft that avoided the transonic region and allowed data to be collected at an angle of attack (AOA) that resulted in a nearly linear aircraft response.

The first three flights were flown early in the day in an attempt to gather data in calm air. In contrast, flights 4 through 11 were flown in the afternoon in an attempt to gather data in turbulent air caused by winds and thermal convection.

The data bands and tolerances for the trim shot at the beginning of each pass are presented in Table 3. Front cockpit head-up display (HUD) altitude and M were used to ensure the test aircraft was on conditions.

Table 3
TRIM SHOT DATA BANDS
AND TOLERANCES

Parameter	Data Band	Tolerance
Altitude (ft)	±1,000	±100
Mach Number	±0.02	±0.01

Data Reduction:

Data reduction consisted of extracting the raw flight data from DAS tapes and processing it on a personal computer before being input into the PCPID to estimate aircraft stability derivatives. An interactive computer program called HDPROCES was written by the HAVE DERIVATIVES team in MATLAB® code to automate this processing (Reference 5). The code for this program is contained in Appendix F.

Each pass, consisting of a set of three pitch doublets and a pitch sweep lasting approximately 60 seconds, was processed individually. First, extraneous data points, data clearly inaccurate in

magnitude or sign, were identified. All data associated with the same time step as the extraneous data point were removed, shortening the complete data file by one line each time that data were removed.

The HDPROCES asked the user to identify a trim shot period on a plot of normal acceleration versus time. The program calculated the power spectral density of normal acceleration for this period using the PSD.M (power spectral density routine) in the MATLAB® Signal Processing Toolbox® (Reference 6). The HDPROCES called the routine and then returned the value of normal acceleration deviation from 1 g at a frequency of 1 radian per second, which was determined to be approximately the short period undamped natural frequency of the F-16B aircraft. The change in g given by the program was used to categorize the results of that particular pass based on the turbulence level definitions given in Table 2.

The user was then prompted by HDPROCES to divide the file into two separate files, one containing the doublets and the other the pitch sweep. The HDPROCES would save the doublet time-history signals in the proper format required by PCPID. The doublets were then ready to be processed by PCPID to estimate stability derivatives.

Further processing of the pitch sweep input and response signals were accomplished by HDPROCES. These five signals (right horizontal stabilator position, AOA, pitch rate, normal acceleration, and pitch angle) were divided into equal length segments which were transformed into the frequency domain via FFT. The transformed segments were averaged for each signal and used to estimate transfer functions. The transfer functions were formed by dividing the cross spectral density of the averaged output and averaged input signal by the power spectral density of the averaged input signal. This operation was performed by the TFE.M (transfer function estimate) routine contained in the MATLAB® Signal Processing Toolbox® (Reference 6). This routine was called by HDPROCES. These averaged frequency responses were then transformed back into the time domain via IFFT as discrete pulse responses. A unit amplitude discrete pulse input was computer generated and saved in the proper format along with the discrete pulse responses to be input into the PCPID for stability derivative estimation.

In order to achieve the best results with PCPID, it was important to update the aircraft mass and inertia model for each pass. The results presented throughout this report are for the center of gravity locations specified for each pass and are not standardized to a particular center of gravity location. The mass and inertia values for a particular pass were given to the user by a FORTRAN program called MASSCALC, written by Mr. Chris Nagy of Quartic Engineering Inc. (Reference 7). Given the total fuel weight of the test aircraft MASSCALC returned the mass, center of gravity location, and moments and products of inertia. These values were hand recorded by the user and input into the PCPID with the corresponding aircraft response time histories. MASSCALC was called by HDPROCESS. The complete code for MASSCALC is presented in Appendix F.

No corrections were made within HDPROCES to the AOA signal for boom upwash or pitch rate effects, however, corrections were made within PCPID for the location of the AOA and normal acceleration sensors relative to the aircraft center of gravity for a given pass.

TEST RESULTS

Calm Air Results Using PCPID Alone (Validation):

The first four passes of flight 1 were accomplished to validate the data reduction process and test aircraft instrumentation. Pitch doublets were performed (Appendix D) at 8,000 feet PA and 0.60 M. The stability derivatives estimated using PCPID alone were compared to the same stability derivatives estimates presented in AFFTC-TLR-92-12, *F-16B Parameter Estimation (PEST)* (Reference 4). The estimates presented in that report were calculated using data taken at the same flight condition, using the same flight test technique and using PCPID alone. The comparison is presented in Table 4.

Although the average value for $C_{m\alpha}$ estimated from the validation passes was of a different sign than the $C_{m\alpha}$ estimated in Reference 4, the fact that $C_{m\alpha}$ was so close to zero in both cases indicated that this sign difference was not significant. As expected, the low positive value of $C_{m\alpha}$ for the HAVE DERIVATIVES test passes did indicate that the nonaugmented F-16B aircraft possessed nearly neutral static longitudinal stability at that flight condition.

The difference in C_{mq} was accepted when it was noted that C_{mq} showed high sensitivity to data processing in previous studies and had less effect on the aircraft short term response than the other three stability derivatives shown in Table 4; therefore, the difference was not considered significant.

The opposite sign for $C_{m\delta e}$ was due to the fact that an opposite sign convention for horizontal stabilator deflection was used in Reference 4, while the sign convention used for the HAVE DERIVATIVES project was in accordance with the current TPS and NASA sign convention.

A value for $C_{N\delta e}$ was calculated for the HAVE DERIVATIVES test passes but was not presented as there was no value given in previous reports against which to compare. The validation of $C_{N\delta e}$ was based on the good consistency of the values for that derivative for each of the four test passes, as well as the small Cramer-Rao bound for the estimate of $C_{N\delta e}$ for each of the four test passes.

Overall, the derivative values presented in Table 4 were determined to be sufficiently close to each other to validate the data reduction processes and test aircraft instrumentation.

Calm Air Results Using PCPID Alone (Basis Data Set):

A basis data set of stability derivative results was developed using PCPID alone on aircraft pitch doublet response data gathered in calm air. This was considered the 'truth source' against which later results were compared. Results from flights 1, 2, and 3 were used to develop this data set.

Success criteria required that data samples were collected for the basis data set until either there was a 95-percent confidence the data set mean estimate was within the desired confidence interval or 30 data samples were collected.

Table 5 presents the mean stability derivative estimate values for the basis data set and the associated confidence level for the desired confidence interval. Also presented in Table 5 are the actual confidence intervals based on a 95-percent confidence level. The mean stability derivative estimate values for the basis data set were the result of averaging 32 separate estimates. The equation used to calculate 95-percent confidence level intervals is given at Appendix A. The stability derivative estimates for each pass in calm air are presented in Table A2.

Although a 95-percent confidence level was not achieved for all of the derivatives, 30 samples had been collected which satisfied the success criteria.

The desired confidence intervals were chosen prior to flight test based on previous experience which indicated that stability derivative values that fluctuate less than the chosen confidence interval will not significantly affect the characteristics of the aircraft response. Since the desired confidence intervals for $C_{m\alpha}$ and $C_{m\delta e}$ were very small, it was difficult to meet them based on a 95-percent confidence level. Nonetheless, the actual confidence intervals were still considered very tight. Performing more passes could have decreased the confidence interval to the desired value.

The confidence interval for C_{mq} was not met due to the inherent difficulty in estimating C_{mq} from flight data. Despite that, the actual confidence interval for C_{mq} was considered acceptable.

Table 4
COMPARISON OF THE DATA REDUCTION PROCESS
AND TEST AIRCRAFT INSTRUMENTATION

Stability Derivative	AFFTC-TLR-92-12[1]	Flight 1 Passes 1-4
$C_{N\alpha}$ (per deg)	0.0658	0.0662
$C_{m\alpha}$ (per deg)	-0.0003	0.0006
C_{mq} (per rad)	-1.5500	-4.5858
$C_{m\delta e}$ (per deg)	0.0123	-0.0122

Notes: 1. Flight Condition: 8,000 Feet Pressure Altitude, Mach 0.60
2. cg range: 36.50 to 36.76 percent mean aerodynamic chord

[1]AFFTC-TLR-92-12 *F-16B Parameter Estimation (PEST)* (Reference 4)

Table 5
CALM AIR MEAN ESTIMATE VALUES AND CONFIDENCE MEASURES USING PCPID ALONE

Stability Derivative	Mean Estimate Value	Desired Confidence Interval	Confidence Level[1] (percent)	Actual Confidence Interval[2]
$C_{N\alpha}$ (per deg)	0.0714	±2.5e-03	99.9	±8.9e-04
$C_{N\delta e}$ (per deg)	0.0132	±2.0e-03	99.9	±6.8e-04
$C_{m\alpha}$ (per deg)	0.0008	±2.5e-04	66.1	±5.3e-04
C_{mq} (per rad)	-3.1380	±4.0e-01	86.3	±5.3e-01
$C_{m\delta e}$ (per deg)	-0.0114	±4.0e-04	70.6	±7.7e-04

Notes:
1. PCPID - Personal Computer Parameter Identification
2. Calculations based on 32 samples
3. Flight Condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Calm Air
4. cg range: 36.15 to 37.38 percent mean aerodynamic chord

[1]Confidence level based on desired confidence interval
[2]Actual confidence interval based on 95-percent confidence level

Table 6 provides a quantitative description of the variation and confidence in the stability derivative estimates of the basis data set. This table presents the average Cramer-Rao bound for each of the five stability derivatives, as well as the standard deviation for each derivative based on 32 estimates. The Cramer-Rao bound was a measure of the confidence PCPID had in the accuracy of each stability derivative estimate. The smaller the Cramer-Rao bound the more confidence PCPID had in the estimate. The Cramer-Rao bound values presented throughout this report are the actual bound values multiplied by a factor of 10. This was based on common practice to closely match the size of the bounds to the scatter of the estimates (Reference 8). The Cramer-Rao bound for each basis data set run is presented in Table A2. The Cramer-Rao bounds were qualitatively judged by the HAVE DERIVATIVES team to be indicative of high PCPID confidence in the stability derivative estimates.

Figure 1 graphically depicts information similar to Table 6. Instead of presenting the mean Cramer-Rao bound for each stability derivative as given in Table 6, Figure 1 presents the Cramer-Rao bound for each individual stability derivative estimate of $C_{N\alpha}$ in the basis data set. The darkened diamonds represent the actual estimate calculated by PCPID for a particular pass. The lines on either side of the diamonds are the confidence bounds calculated to be the Cramer-Rao bound for each of the 32 stability derivative estimates. Figure 1 shows the scatter of the estimates as well.

The AOA along the horizontal axis of Figure 1 was the average AOA for that particular run from which the estimate was calculated. The scatter of points between approximately 1.5 to 2.5 degrees average AOA was due to the fact that average AOA varied during each flight as fuel was burned causing the aircraft's center of gravity to shift slightly.

The important scatter to note is along the vertical axis. Larger scatter would indicate less precision, and hence, less confidence in the estimate values. Associated with that is the size of the Cramer-Rao bound as displayed by bars for each estimate. As mentioned earlier, a smaller Cramer-Rao bound indicates higher confidence in the accuracy of the estimate. Following these guidelines, the HAVE DERIVATIVES test team qualitatively determined the scatter and Cramer-Rao bounds of the basis data set to be small and indicative of high confidence in the precision and accuracy of the estimates.

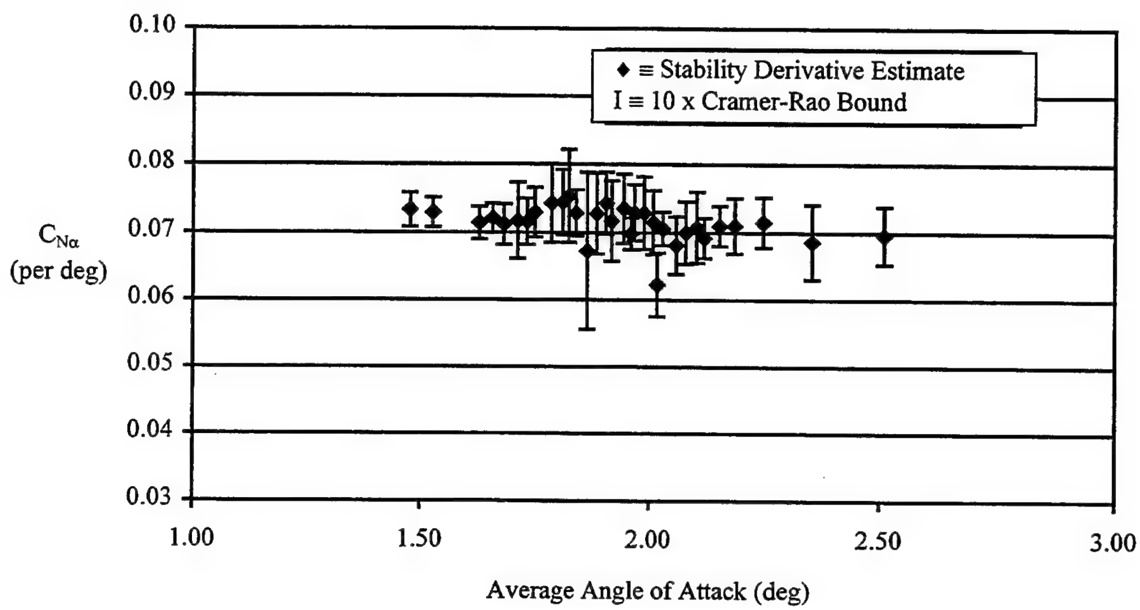
Figure 2 presents a representative comparison between the actual time-history responses of the test aircraft to the given doublet input and PCPID computed time histories. The computed time histories were calculated by PCPID during each iteration of a parameter estimation run using the actual measured input and current estimates for $C_{N\alpha}$, $C_{N\delta e}$, $C_{m\alpha}$, C_{mq}, and $C_{m\delta e}$ in its equations of motion. The closer the computed time histories were to the actual responses, the higher the confidence in the final PCPID stability derivative estimates. The excellent time-history matches shown in Figure 2 were typical for the basis data set and were qualitatively judged to indicate high confidence in the derivative estimates used to create the computed time histories.

Table 6
STANDARD DEVIATION AND MEAN CRAMER-RAO BOUND USING PCPID ALONE ON CALM AIR DATA

Stability Derivative	Standard Deviation[1]	Mean Cramer-Rao Bound[1,2]
$C_{N\alpha}$ (per deg)	0.0025	±4.4e-03
$C_{N\delta e}$ (per deg)	0.0019	±4.8e-03
$C_{m\alpha}$ (per deg)	0.0015	±5.7e-04
C_{mq} (per rad)	1.4808	±1.1e-00
$C_{m\delta e}$ (per deg)	0.0021	±9.9e-04

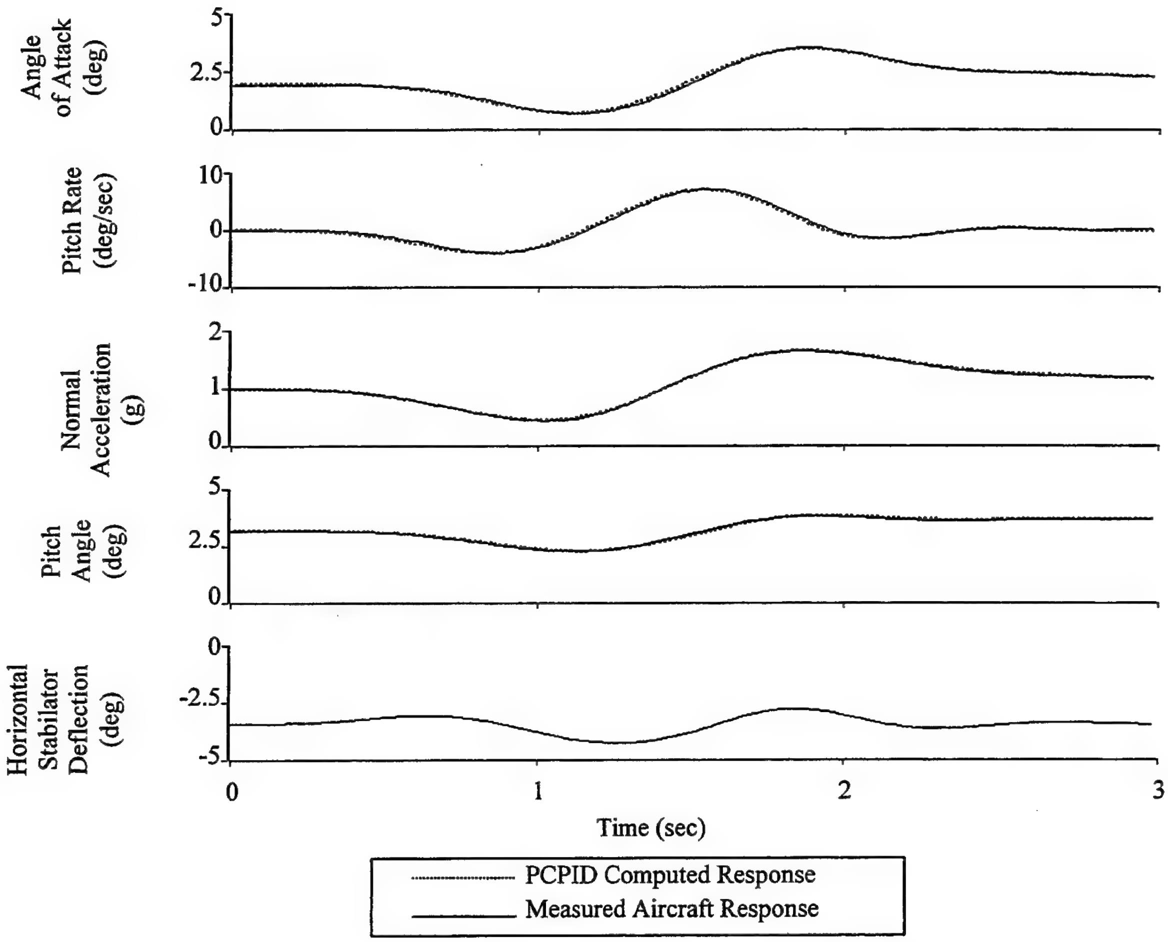
Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Calm Air
3. cg range: 36.15 to 37.38 percent mean aerodynamic chord

[1]Based on 32 samples
[2]Cramer-Rao bounds have been multiplied by a factor of 10



Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Calm Air
2. cg range: 36.15 to 37.38 percent mean aerodynamic chord
3. Cramer-Rao bounds have been multiplied by a factor of 10

Figure 1 Example Stability Derivative Estimates and Cramer-Rao Bound Using PCPID Alone on Calm Air Data



Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Calm Air
2. cg location: 36.50 percent mean aerodynamic chord

Figure 2 Example Time-History Matches Using PCPID Alone on Calm Air Data

Complementing the qualitative time-history matches were the cost function values. The cost function values were a quantitative indication of how closely PCPID computed time histories matched the measured time histories of angle of attack (α), pitch rate (q), pitch angle (θ) and normal acceleration (n_z). Smaller cost function values indicated a closer match of the computed time histories to the measured time histories. Consequently, the derivative estimates for a run with smaller cost function values were considered more accurate than those estimates associated with larger cost function values. The values of the cost functions were equalized at unity for the first 10 passes in calm air by varying weightings associated with AOA, pitch rate, pitch angle, and normal acceleration response parameters within the PCPID. These weightings were then used during data analysis for all subsequent runs using doublet responses and PCPID alone.

Table 7 presents the average cost function value for each output response variable used to develop the basis data set along with the associated weightings used in PCPID. The individual cost function values for each basis data set run are presented in Appendix B.

Calm Air Results Using the HAVE DERIVATIVES Process with PCPID:

This section presents the stability derivative estimate results found using the HAVE DERIVATIVES process with PCPID, on calm air data. Results from simulations using AT-37B and F-16B computer models are presented first to lay the foundation for the flight results that follow.

Table 7
RESPONSE WEIGHTING AND MEAN COST FUNCTION VALUES USING PCPID ALONE ON CALM AIR DATA

Output Response Parameter	Weighting Values	Mean Cost Function Values[1]
Angle of Attack (deg)	23	3.24
Pitch Rate (deg/sec)	3	2.11
Pitch Angle (deg)	14	1.85
Normal Acceleration (g)	60	3.48

Note: PCPID - Personal Computer Parameter Identification

[1]Based on 32 samples

According to theory, the discrete pulse responses given by the IFFT of the HAVE DERIVATIVES process should closely approximate the ideal impulse responses of the test aircraft. This theory was validated in computer simulation at AFIT using an AT-37B aircraft model. The AT-37B computer model was constructed within a MATLAB® script file titled, T37_SIM, written by Captain Hoffman. The model was a linear, 2-degree of freedom, longitudinal state-space model using the short period approximation where pitch angle response was disregarded. The parameter values used in the model were provided by the USAF TPS based on model validation flight tests with the AT-37B aircraft.

The validation was accomplished by comparing the discrete pulse responses rendered by the HAVE DERIVATIVES process to ideal impulse responses of the same AT-37B model. The discrete pulse responses were generated within T37_SIM by processing a broadband elevator input, and the responses to that input, through the HAVE DERIVATIVES process. The broadband input was found to give the best ensemble averaging results because it possessed uniformly distributed frequency content. The ideal impulse responses were generated within T37_SIM using the MATLAB® Control System Toolbox® unit impulse response routine (Reference 10). When presented on the same axes, the discrete pulse responses were nearly identical to the ideal impulse responses.

To estimate stability derivatives from the discrete pulse responses, PCPID required an input time-history that correlated with those responses. Because a true impulse function is impossible to represent in discrete time, a simulated ideal impulse input was created within T37_SIM. To be consistent with theory, the simulated ideal impulse was constructed to have unity area. A good approximation was found to be an input one time step wide and (1/one time step) in amplitude. This equated to a signal 1/67 second wide and 67 degrees in amplitude based on the 67-hertz sampling rate used in all of the simulations. The time histories of the responses from a linear simulation, using the simulated ideal impulse as an input, were nearly identical to the ideal impulse responses produced using the unit impulse response routine mentioned earlier. This validated the simulated ideal impulse as a good approximation of the theoretical ideal impulse.

Because the discrete pulse responses from the HAVE DERIVATIVES process and the responses to the simulated ideal impulse were nearly identical, it was concluded that the simulated ideal impulse input correlated well with the discrete pulse responses. This was supported by simulation results showing that the coherence of the simulated ideal impulse to each of the responses was equal to one at all frequencies when no noise was present. The approach developed was to import the simulated ideal impulse into PCPID along with the discrete pulse responses. The PCPID was able to match the discrete pulse responses very well resulting in excellent stability derivative estimation results in both calm and turbulent conditions. Those results validated the approach that was adopted for all runs involving the HAVE DERIVATIVES process with PCPID.

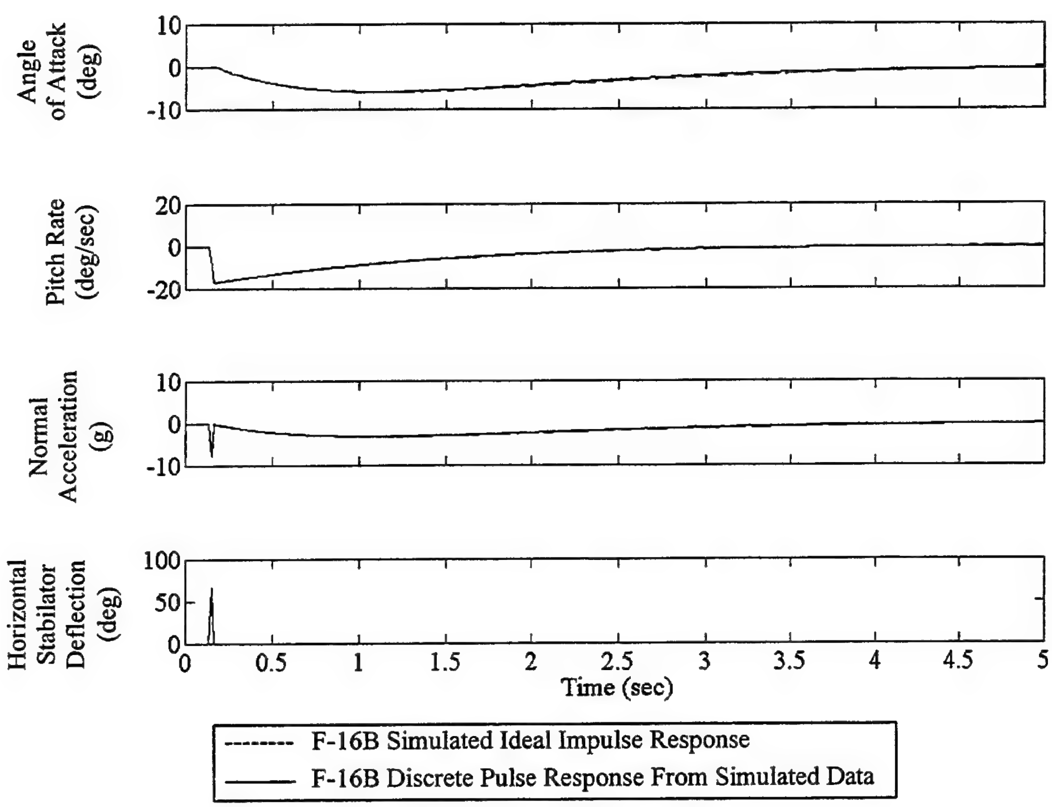
The T37_SIM program, now called F16_SIM, was modified and used by the HAVE DERIVATIVES team to validate the theory with the F-16B model. The flight condition in the program was changed to the desired HAVE DERIVATIVES test condition of 4,000 feet PA and 0.65 M. Another modification included changing the aircraft model in the program to that of the F-16B test aircraft. The longitudinal stability derivatives were the mean values from the basis data set, as presented in Table 5, rounded to one significant figure. Finally, the mass and inertia properties were updated to reflect the test aircraft's

mass and inertia midway through a test flight; assuming an average fuel burn.

The first simulation resulted in divergent responses to a simulated ideal impulse input for all three states: angle of attack, pitch rate, and normal acceleration. This was due to the positive $C_{m\alpha}$ value of 0.0008 per degree. To produce a dynamically stable longitudinal response, $C_{m\alpha}$ was changed to -0.0001 per degree and the simulation was repeated. It should be noted that although the mean value of $C_{m\alpha}$ for the basis data set of 32 samples was 0.0008 per degree, there were 11 passes where $C_{m\alpha}$ was estimated to be equal to or more negative than -0.0001 per degree, with the most negative being -0.0012 per degree. The results of the second simulation, presented in Figure 3, were much better.

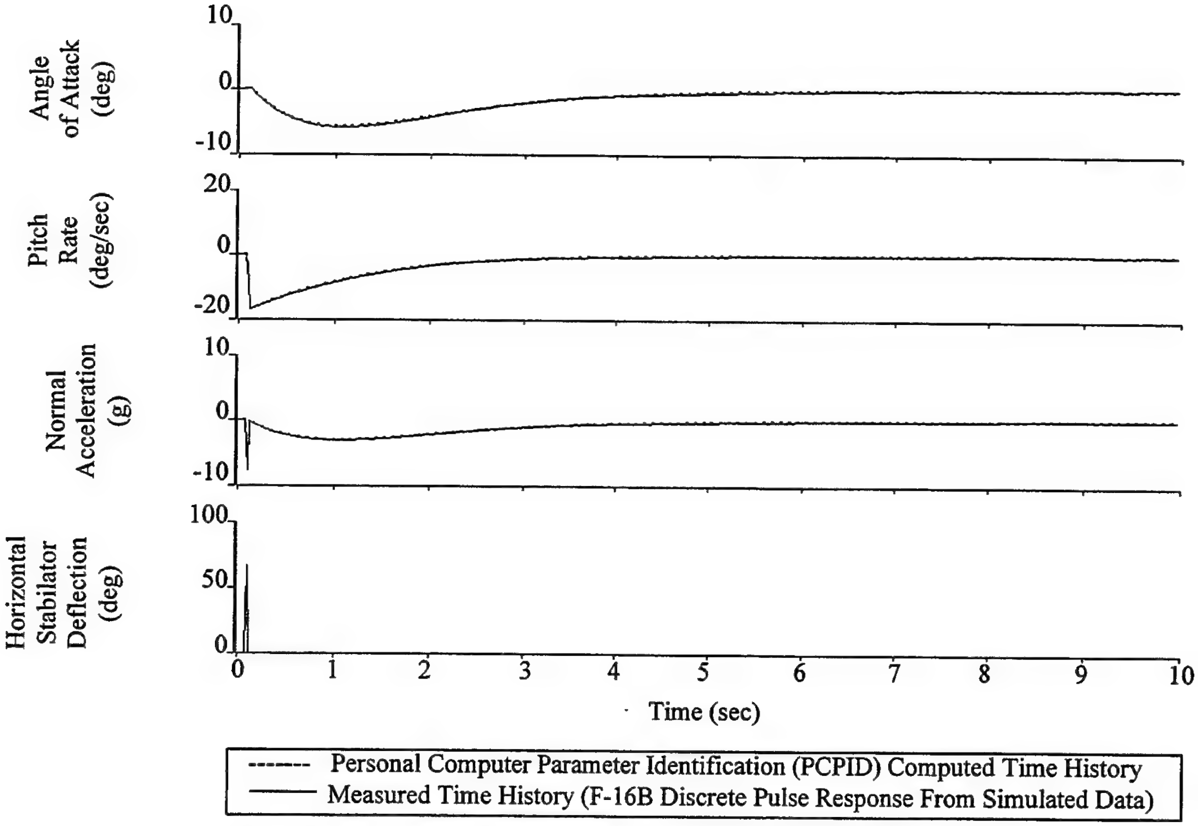
Figure 3 shows that the matches of the discrete pulse responses to the simulated ideal impulse responses were excellent, as with the AT-37B simulations. The horizontal stabilator simulated ideal impulse input and the discrete pulse responses from the HAVE DERIVATIVES process were entered into the PCPID. The time-history matches are presented in Figure 4.

The PCPID matched the simulated discrete pulse response time histories almost perfectly. The numerical results presented in Table 8 contain the derivative values used in the simulation model along with the PCPID estimates and their Cramer-Rao bounds.



Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, No Noise
2. cg location: 36.76 percent mean aerodynamic chord

Figure 3 F-16B Simulated Ideal Impulse Responses and Discrete Pulse Responses From Simulated Data



Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, No Noise
2. cg location: 36.76 percent mean aerodynamic chord

Figure 4 Matches of PCPID Computed Time Histories to F-16B Discrete Pulse Responses From Simulated Data

Table 8
F-16B SIMULATION STABILITY DERIVATIVE TRUE VALUES, PCPID ESTIMATED VALUES AND CRAMER-RAO BOUNDS

Stability Derivative	True Value	Estimated Value	Cramer-Rao bound[1]
$C_{N\alpha}$ (per deg)	0.0700	0.07140	±9.6e-04
$C_{N\delta e}$ (per deg)	0.0100	0.01060	±6.9e-04
$C_{m\alpha}$ (per deg)	-0.0001	-0.00005	±2.3e-05
C_{mq} (per rad)	-3.0000	-3.36000	±1.3e-01
$C_{m\delta e}$ (per deg)	-0.0100	-0.01020	±1.1e-04

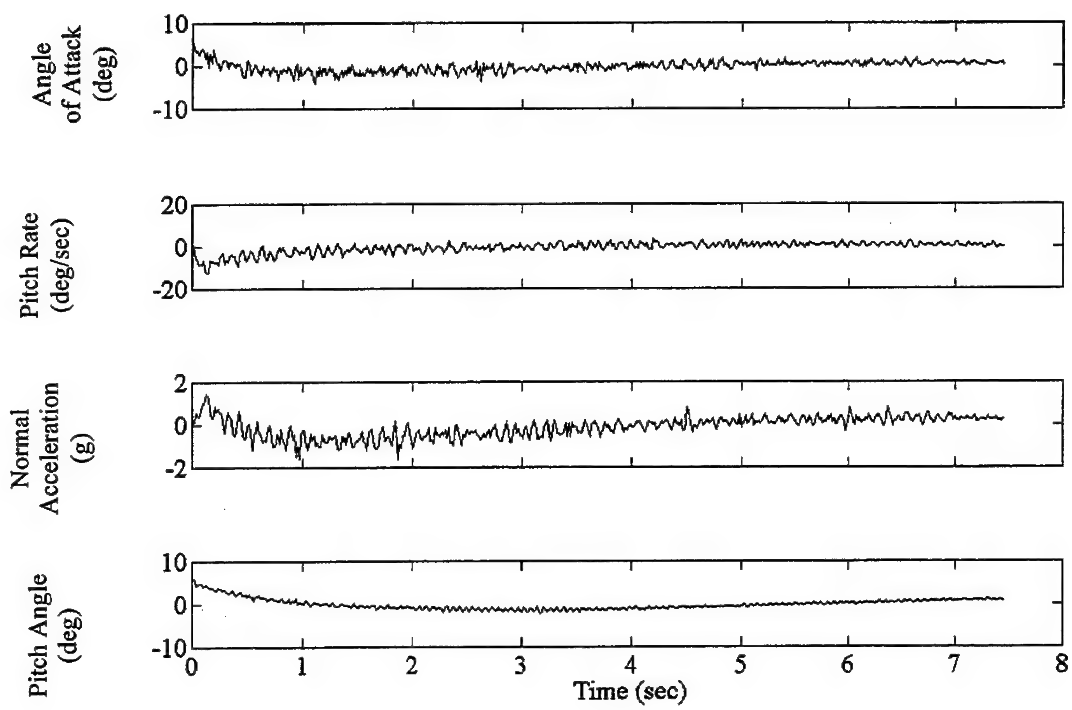
Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number
2. cg location: 36.76 percent mean aerodynamic chord
3. PCPID - Personal Computer Parameter Identification

[1]Cramer-Rao bounds have been multiplied by a factor of 10

The very small Cramer-Rao bounds indicated the high confidence PCPID had in the accuracy of the F-16B simulation estimates which were very close to the true estimate values that were used to build the F-16B simulation model. The minor deviations were due to estimation errors induced by the HAVE DERIVATIVES process as well as the nature of the parameter estimation problem. The parameter estimation algorithm in PCPID was only able to give the most likely estimate of the derivatives as the program did not know the true values. With this understanding, these results indicated that PCPID had little problem estimating the F-16B simulation model stability derivatives with high confidence in those estimates. The conclusion drawn was that the HAVE DERIVATIVES process worked well with the F-16B short period approximation model in simulation as it had with the AT-37B model. The HAVE DERIVATIVES team, therefore, expected the process to be effective with F-16B flight data. The results from using the HAVE DERIVATIVES process with PCPID, on calm air data are presented next.

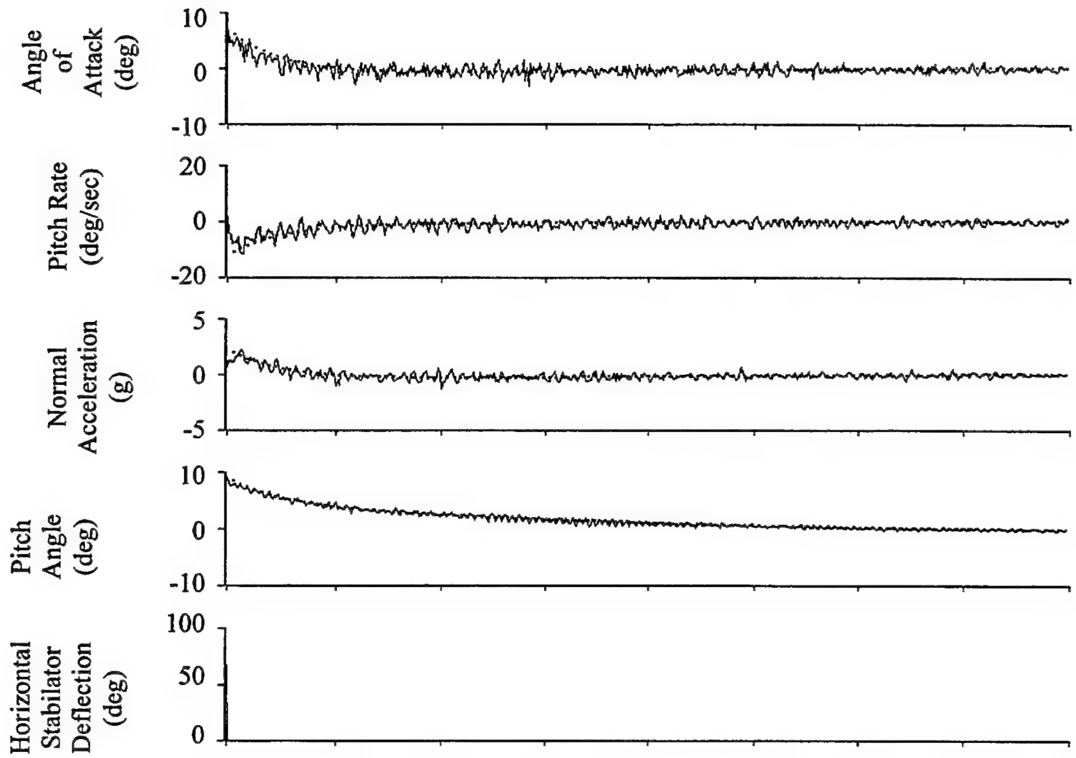
Pitch sweep and response time histories from the test flights were processed postflight using the MATLAB® script file HDPROCES.M, as discussed earlier, and in Appendix F. A typical set of discrete pulse responses rendered by the HAVE DERIVATIVES process are shown in Figure 5.

Although the responses were generally of the correct shape, the high frequency noise in the signals made it difficult for PCPID to estimate derivatives. The responses shown in Figure 5 were imported into PCPID along with the simulated ideal impulse input. The resulting time-history matches are shown in Figure 6.



Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Calm Air
2. cg location: 37.03 percent mean aerodynamic chord

Figure 5 Discrete Pulse Responses Using the HAVE DERIVATIVES Process on Calm Air Data



Notes: 1. Flight Condition: 4,000 Feet Pressure Altitude,0.65 Mach Number, Calm Air
2. cg location: 37.03 percent mean aerodynamic chord

Figure 6 Matches of PCPID Computed Time Histories to Unfiltered F-16B Discrete Pulse Responses From HAVE DERIVATIVES Process With Calm Air Data

Note that the simulated ideal impulse is located at the first time step to align with the first point of the discrete pulse responses. The PCPID attempted to match the underlying responses by disregarding the high frequency components and computing time histories that matched the general shape of the measured time histories. The resulting derivative values and Cramer-Rao bounds are given in Table 9, along with associated mean values from the basis data set.

Although the estimate for $C_{m\alpha}$ appears to be accurate, based on its small Cramer-Rao bound and small deviation from the basis data set mean estimate for $C_{m\alpha}$, the results for the other four derivatives were not acceptable. All four had a larger Cramer-Rao bound than the basis data set values for the same derivatives, and each was at least two standard deviations from the basis data set mean estimate for their associated derivative. The results for $C_{N\alpha}$ and $C_{N\delta e}$ were particularly poor. Also, it should be noted that the HAVE DERIVATIVES results were very sensitive to response weighting in PCPID, requiring considerable effort to achieve the results shown in Table 9. Consequently, the HAVE DERIVATIVES team determined that further data processing would be pointless unless the high frequency content on the discrete pulse responses could be reduced significantly or eliminated.

One method of minimizing the noise was to append frequency sweep data from several passes to artificially increase the maneuver length, thereby increasing the number of ensembles that would be averaged within the HAVE DERIVATIVES process. This approach required excessive flight data producing only marginal improvement over processing one pass so was therefore, not adopted.

Table 9
UNFILTERED RESULTS FROM USING THE HAVE DERIVATIVES PROCESS WITH PCPID ON CALM AIR DATA AND ASSOCIATED BASIS DATA SET RESULTS

Stability Derivative	Basis Data Set Results[1]		Unfiltered HAVE DERIVATIVES Results[2]		
	Mean Estimate	Mean Cramer-Rao Bound	Estimate	Cramer-Rao Bound[4]	Deviation from Basis[3]
$C_{N\alpha}$ (per deg)	0.0714	±4.4e-03	0.0452	±1.1e-02	10.48
$C_{N\delta e}$ (per deg)	0.0132	±4.8e-03	0.0417	±6.6e-03	15.00
$C_{m\alpha}$ (per deg)	0.0008	±5.7e-04	0.0007	±4.2e-04	0.07
C_{mq} (per rad)	-3.1380	±1.1e-00	-6.4184	±1.2e-00	2.22
$C_{m\delta e}$ (per deg)	-0.0114	±9.9e-04	-0.0166	±2.0e-03	2.48

Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number
2. cg location: 37.03 percent mean aerodynamic chord
3. PCPID – Personal Computer Parameter Identification

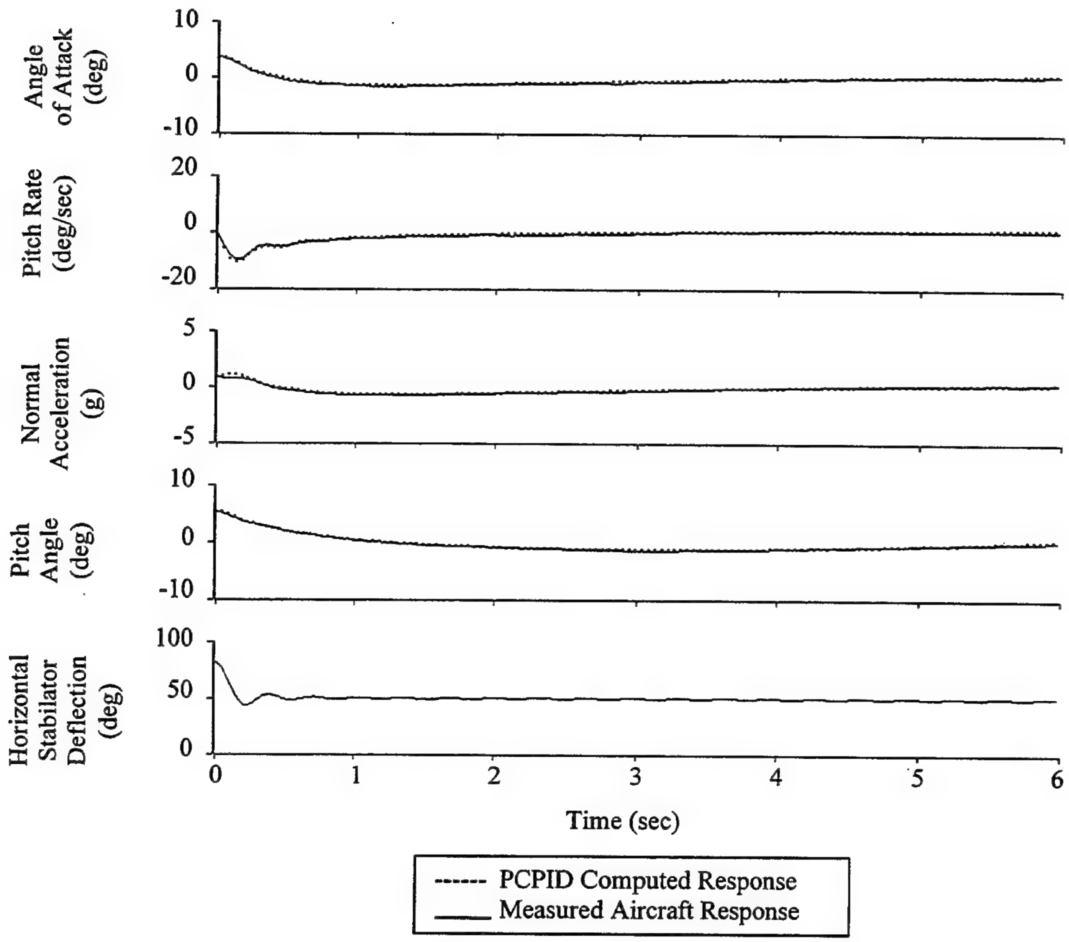
[1]Based on 32 samples
[2]Based on 1 sample
[3]Number of standard deviations from basis data set mean estimate
[4]Cramer-Rao bounds have been multiplied by a factor of 10

The source of the problems appeared to be the lack of uniformly distributed frequency content in the frequency sweep input and responses. Recall that a broadband input was used in simulation with excellent results. Because the broadband input possessed nearly uniform frequency content, the ensemble averaging was effective at minimizing variance (noise). As more ensembles were averaged, the random components in the ensembles were minimized while the repetitive components, which defined the frequency responses of the aircraft, were amplified. In contrast, the frequency sweeps used in flight did not have uniformly distributed frequency content. Although the sweeps produced good frequency responses up to 10 radians per second, they were not effective with ensemble averaging. A uniformly distributed frequency content input could be applied through a programmed test input test set and would give better results with the ensemble averaging step of the HAVE DERIVATIVES process. **The HAVE DERIVATIVES process should be evaluated using a broadband programmed test input in flight. (R1)**

Although the HAVE DERIVATIVES team determined that the ensemble averaging step of the HAVE DERIVATIVES process would not be as effective with a frequency sweep flight test input, the team was still interested in evaluating the other steps of the HAVE DERIVATIVES process. Because the contamination of the discrete pulse responses was due mainly to high frequency measurement noise, low-pass Butterworth filters were applied to the response signals prior to putting them through the HAVE DERIVATIVES process.

A Butterworth-type filter was chosen for its desirable property of being maximally flat in the passband and because it is commonly used and recognized at the AFFTC. Various combinations of filter order and frequency cutoff were examined. It was found that higher order filters could be used without noticeable increases in computation time. A ninth-order filter was chosen as a good tradeoff between steep rolloff and filter complexity. The cutoff frequency needed to be high enough so as not to distort the low frequency responses while being low enough to minimize the higher frequency noise. A cutoff frequency of 20 radians per second was determined to be the optimal choice for this project. To avoid adding phase lag to the signals, the filters were applied both forward and backwards in time using the FILTFILT.M routine in MATLAB's® Signal Processing Toolbox® (Reference 6).

The best results were achieved by filtering only the responses and not the frequency sweep input signal prior to HAVE DERIVATIVES processing. However, there was concern that the simulated ideal impulse input would no longer correlate with the discrete pulse responses that had been shaped by the filters applied prior to the HAVE DERIVATIVES process. This concern was validated with PCPID results as the $C_{m\delta e}$ estimates were about half the magnitude of the basis data set mean estimate of $C_{m\delta e}$. To achieve a better match between the simulated ideal impulse input and the filtered discrete pulse responses, the same Butterworth filter was applied to the simulated ideal impulse signal as shown in a typical case (Figure 7).



Notes: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Calm Air
2. cg location: 37.03 percent mean aerodynamic chord

Figure 7 Matches of PCPID Computed Time Histories to Filtered F-16B Discrete Pulse Responses From HAVE DERIVATIVES Process With Calm Air Data

The time-history matches presented in Figure 7 were satisfactory with the only exception being the initial few points of the normal acceleration response. Figure 7 clearly shows that the low-pass filters were able to eliminate most of the high frequency noise that was present on the same signals (shown unfiltered in Figure 6). Table 10 provides a comparison of the filtered HAVE DERIVATIVES results along with the associated basis data set results.

Comparing the filtered HAVE DERIVATIVES results from Table 10 to the unfiltered HAVE DERIVATIVES results from Table 9 revealed that improvement was attained through the use of the filters. The Cramer-Rao bounds for all five filtered estimates were smaller than the unfiltered estimate Cramer-Rao bounds. In fact, the filtered estimate Cramer-Rao bounds were smaller than the basis data set mean Cramer-Rao bounds for all derivatives except $C_{N\delta e}$, which was slightly larger than the associated basis data set value. This was considered significant as the comparison was made between the basis data set Cramer-Rao bounds, which were an average of 32 samples, and the single filtered HAVE DERIVATIVES sample. The conclusion drawn was that the filtering resulted in smaller Cramer-Rao bounds that indicated greater confidence in the accuracy of the derivative estimates.

The comparison of the filtered estimate deviations from the basis data set to the unfiltered estimate deviations from the basis data set was not as

Table 10
FILTERED RESULTS FROM USING THE HAVE DERIVATIVES PROCESS WITH PCPID ON CALM AIR DATA AND ASSOCIATED BASIS DATA SET RESULTS

Stability Derivative	Basis Data Set Results[1]		Filtered HAVE DERIVATIVES Results[2]		
	Mean Estimate	Mean Cramer-Rao Bound	Estimate	Cramer-Rao Bound[4]	Deviation from Basis[3]
$C_{N\alpha}$ (per deg)	0.0714	±4.4e-03	0.0661	±4.2e-03	2.12
$C_{N\delta e}$ (per deg)	0.0132	±4.8e-03	0.0182	±5.1e-03	2.63
$C_{m\alpha}$ (per deg)	0.0008	±5.7e-04	0.0007	±1.1e-04	0.07
C_{mq} (per rad)	-3.1380	±1.1e-00	-7.0223	±3.9e-01	2.62
$C_{m\delta e}$ (per deg)	-0.0114	±9.9e-04	-0.0132	±5.3e-04	0.86

Note: 1. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number
2. cg location: 37.03 percent mean aerodynamic chord
3. PCPID - Personal Computer Parameter Identification

[1]Based on 32 samples
[2]Based on 1 sample
[3]Number of standard deviations from basis data set mean estimate
[4]Cramer-Rao bounds have been multiplied by a factor of 10

conclusive. Although the deviations of the filtered estimates were much smaller for $C_{N\alpha}$, $C_{N\delta e}$, and $C_{m\delta e}$, the deviation of $C_{m\alpha}$ was the same while the deviation of the filtered C_{mq} was slightly larger. Also, three of the five filtered HAVE DERIVATIVES estimates were still greater than two standard deviations from the basis data set mean estimates. That much deviation was considered unacceptable. The HAVE DERIVATIVES team concluded that although the filtering improved the Cramer-Rao bounds, the large deviations indicated that there were still some problems with the approach of using low-pass Butterworth filters to remove the noise. The team suspected that the low cutoff frequency of the filters resulted in corruption of some of the dynamics that PCPID was attempting to match. Also, it was likely that the filters affected the high frequency simulated ideal impulse signal more than the low frequency responses, resulting in degraded correlation between the input and response signals. The only conclusion that the HAVE DERIVATIVES team could make was that low-pass filters should not be used to remove noise unless absolutely necessary, and then only at a cutoff frequency high enough above the dynamics of interest so as not to corrupt those dynamics.

Turbulent Air Results Using PCPID Alone:

This section presents the comparison of the turbulent air stability derivative estimation results found using PCPID alone to the basis results presented earlier. Only data from flights 4 through 11 accomplished in turbulent air (see Table 2) were used to develop this data set.

Table 11 presents mean stability derivative estimate values and confidence intervals based on a 95-percent confidence level. The mean stability derivative estimate values were the result of averaging 52 separate estimates for the turbulent air data set and 32 separate estimates for the basis data set. The equation used to calculate 95-percent confidence level intervals is given in Appendix A. The stability derivative estimates for each pass in turbulent air are presented in Table A3.

The confidence intervals presented in Table 11, corresponding to a 95-percent confidence level, overlapped for all derivatives except $C_{N\delta e}$. Despite this, the turbulent air $C_{N\delta e}$ value was close enough for the HAVE DERIVATIVES team to conclude that the stability derivatives calculated using PCPID alone on turbulent air are of the same population as the basis data set.

The standard deviation and mean Cramer-Rao bound are given in Table 12 for each derivative of the basis data set and turbulent air data set. Recall that the Cramer-Rao bound was a measure of confidence PCPID had in each stability derivative estimate. The smaller the Cramer-Rao bound, the

Table 11
BASIS DATA SET AND TURBULENT AIR MEAN ESTIMATE VALUES AND CONFIDENCE INTERVALS USING PCPID ALONE

Stability Derivative	Calm Air, PCPID Alone (Basis Data Set)		Turbulent Air PCPID Alone	
	Mean Estimate Value[1]	Confidence Interval[2]	Mean Estimate Value[3]	Confidence Interval[4]
$C_{N\alpha}$ (per deg)	0.0714	±8.9e-04	0.0693	±1.67e-03
$C_{N\delta e}$ (per deg)	0.0132	±6.8e-04	0.0174	±2.26e-03
$C_{m\alpha}$ (per deg)	0.0008	±5.3e-04	0.0010	±3.99e-04
C_{mq} (per rad)	-3.1380	±5.3e-01	-3.5564	±7.91e-01
$C_{m\delta e}$ (per deg)	-0.0114	±7.7e-04	-0.0111	±7.80e-04

Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight Condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number

[1]cg range: 36.15 to 37.38 percent mean aerodynamic chord (MAC)
[2]Confidence interval based on 95-percent confidence level and 32 samples
[3]cg range: 37.38 to 35.88 percent MAC
[4]Confidence interval based on 95-percent confidence level and 52 samples

Table 12
F-16B TURBULENT AIR STABILITY DERIVATIVE STANDARD DEVIATIONS AND MEAN CRAMER-RAO BOUNDS USING PCPID ALONE

Stability Derivative	Basis Data Set Calm Air, PCPID Alone [1,2]		Turbulent Air PCPID Alone[3,4]	
	Standard Deviation	Mean Cramer-Rao Bound	Standard Deviation	Mean Cramer-Rao Bound
$C_{N\alpha}$ (per deg)	0.0025	±4.4e-03	0.0060	±6.5e-03
$C_{N\delta e}$ (per deg)	0.0019	±4.8e-03	0.0081	±8.6e-03
$C_{m\alpha}$ (per deg)	0.0015	±5.7e-04	0.0014	±8.0e-04
C_{mq} (per rad)	1.4808	±1.1e-00	2.8403	±1.9e-00
$C_{m\delta e}$ (per deg)	0.0021	±9.9e-04	0.0028	±1.6e-03

Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight Condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number

[1]cg range: 37.38 to 36.15 percent mean aerodynamic chord (MAC)
[2]Based on 32 samples
[3]cg range: 37.38 to 35.88 percent MAC
[4]Based on 52 samples

more confidence PCPID had in the estimate. The Cramer-Rao bounds for each turbulent air data set run are presented in Table A3.

The standard deviation for each turbulent air data set stability derivative was larger than its corresponding basis data set derivative except for $C_{m\alpha}$. However, the standard deviation of $C_{m\alpha}$ was the smallest for both data sets which indicated that PCPID was able to achieve the best precision in estimating $C_{m\alpha}$. Additionally, the turbulent $C_{m\alpha}$ estimate was nearly identical to the basis $C_{m\alpha}$ estimate; $C_{m\alpha}$ had the lowest mean Cramer-Rao bound in both sets. These results indicated that PCPID was able to achieve its best results when estimating $C_{m\alpha}$, even when turbulence was present.

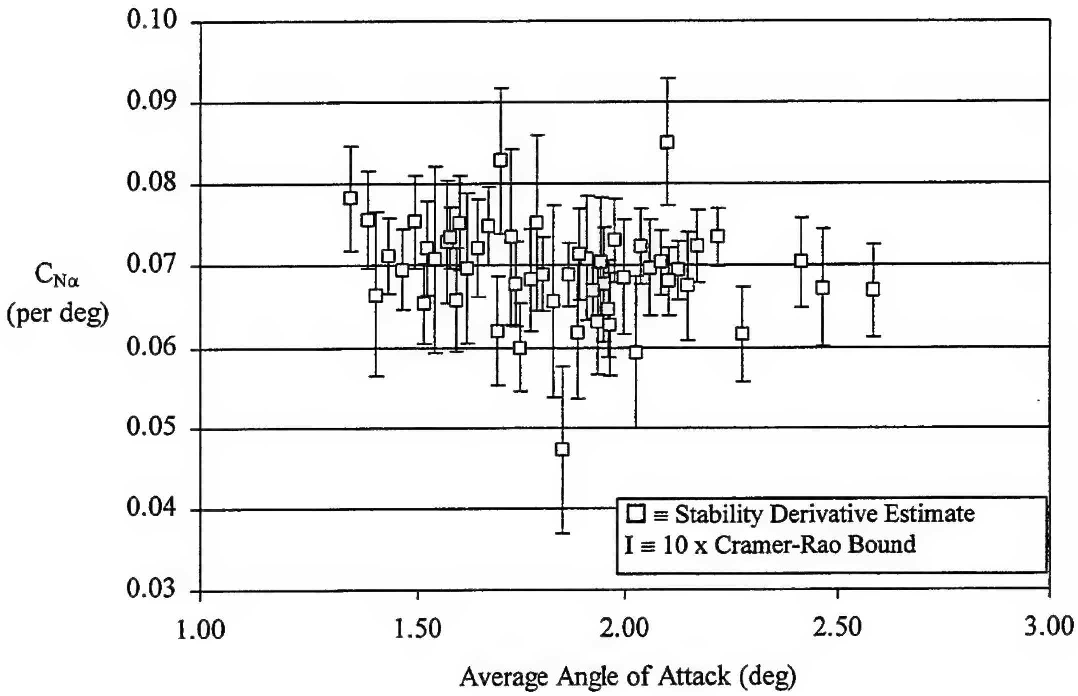
As expected, the turbulent data set mean Cramer-Rao bound was larger than the corresponding basis data set mean Cramer-Rao bound for each of the derivatives. Overall, the standard deviation and mean Cramer-Rao bound results indicated that there was

greater scatter within the turbulent data set and less confidence in the individual estimates. Figure 8 presents the Cramer-Rao bound for each individual estimate of $C_{N\alpha}$ in the turbulent data set and shows the scatter of the turbulent data set estimates.

The vertical scatter of the turbulent air data in Figure 8 was greater than the calm air (basis) data shown in Figure 1, while the individual turbulent air estimate Cramer-Rao bounds were generally larger. The larger vertical scatter in Figure 8 indicated less precision, and hence, less confidence in the estimate values, while the larger Cramer-Rao bounds for the turbulent air data set indicated lower confidence in the accuracy of the estimates.

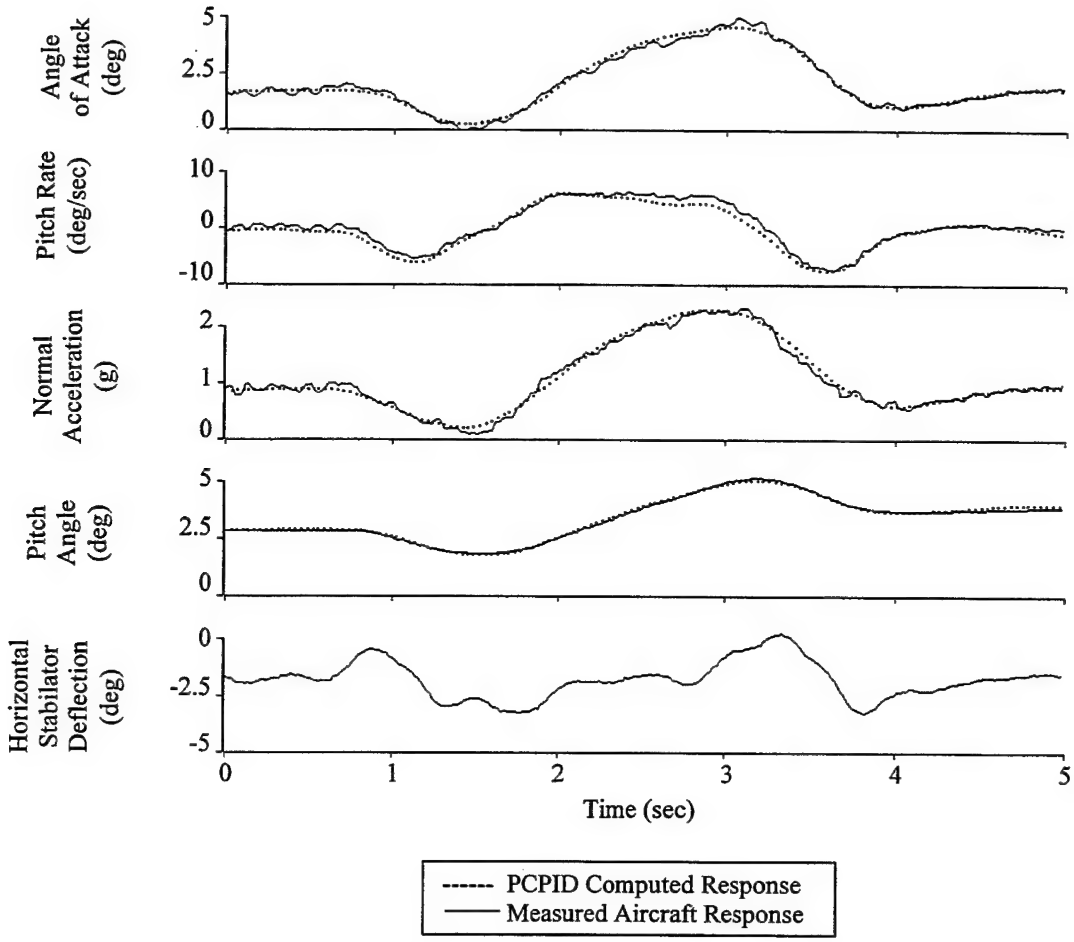
Figure 9 presents a representative comparison between the test aircraft turbulent air time-history responses to the given doublet input and the PCPID computed time histories.

The turbulent air time-history matches in Figure 9 were unsatisfactory as compared to the calm air time-history matches shown in Figure 2. The parameter estimation routine in PCPID had a difficult time discerning the true aircraft responses due to the doublet input from the response variations due to turbulence. The solution it converged to was a compromise that produced the unsatisfactory results discussed earlier in this section of the report.



Notes: 1. Flight Condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Turbulent Air
2. cg range: 37.38 to 36.15 percent mean aerodynamic chord
3. Cramer-Rao bounds have been multiplied by a factor of 10
4. PCPID - Personal Computer Parameter Identification

Figure 8 Example F-16B Turbulent Air Stability Derivative Estimates and Cramer-Rao Bounds Using PCPID Alone



Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight Condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number, Turbulent Air
3. cg location: 36.85 percent mean aerodynamic chord

Figure 9 Example F-16B Turbulent Air Time-History Matches Using PCPID Alone

Complementing the qualitative time-history matches were the numerical cost function values. Recall that the derivative estimates for a run with smaller cost function values were considered more accurate than those estimates associated with larger cost function values. Mean cost function values for the basis data set and turbulent air data set are shown in Table 13.

As expected, the turbulent air data set had larger mean cost function values which indicated less accuracy in the estimates given by PCPID for that data set when compared to the basis data set. The higher cost function values for the turbulent air data set were due to unsatisfactory time-history matches like those shown in Figure 9.

Turbulent Air Results Using HAVE DERIVATIVES Process with PCPID:

Turbulent air results using the HAVE DERIVATIVES process with PCPID are presented in this section. The F-16B simulation results are first discussed to illustrate the effectiveness of the HAVE DERIVATIVES process with the F-16B model. Problems encountered when using the HAVE DERIVATIVES process with turbulent flight data are presented next including results obtained with the addition of low-pass Butterworth filters.

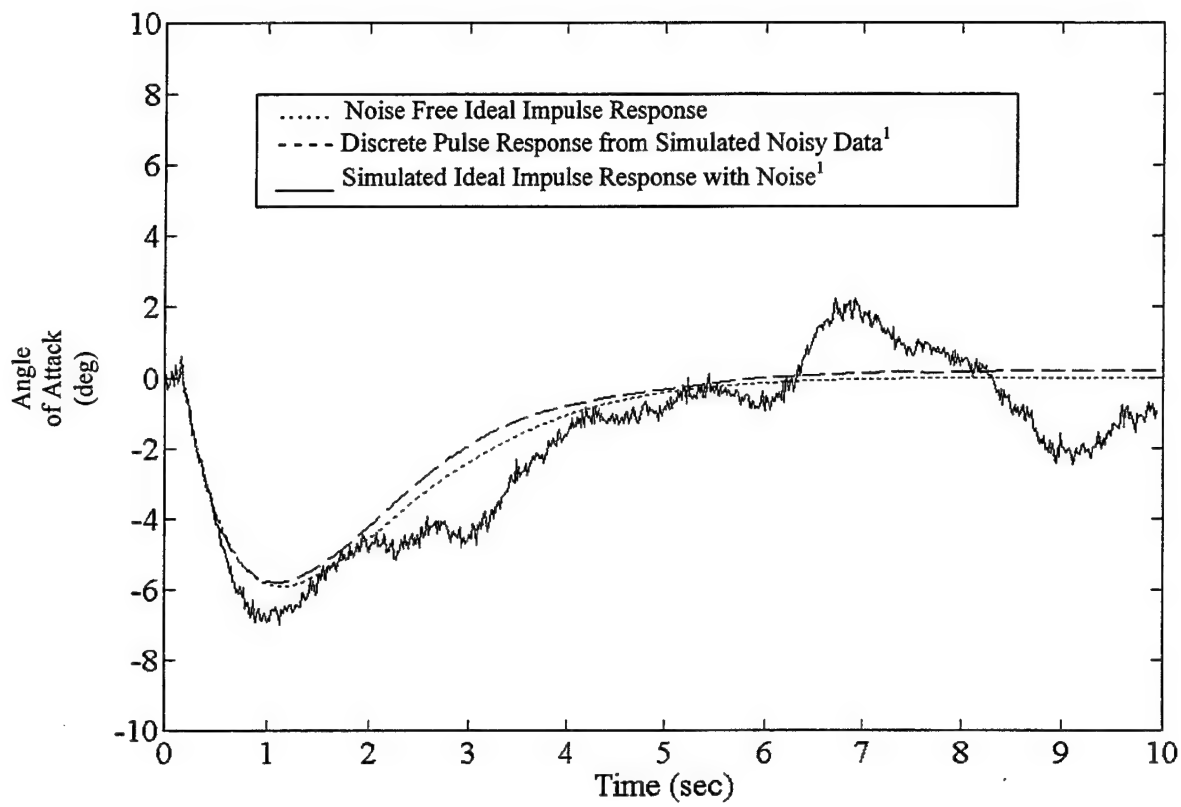
Simulated F-16B AOA responses are shown in Figure 10 to highlight the degradation due to process and measurement noises, and to demonstrate the

Table 13
F-16B MEAN COST FUNCTION VALUES USING PCPID ALONE

Output Response Parameter	Calm Air, PCPID Alone (Basis Data Set)[1]		Turbulent Air PCPID Alone[3]	
	Weighting Value	Mean Cost Function Value[2]	Weighting Value	Mean Cost Function Value[4]
Angle of Attack (deg)	23	3.24	23	16.88
Pitch Rate (deg/sec)	3	2.11	3	4.49
Pitch Angle (deg)	14	1.85	14	5.82
Normal Acceleration (g)	60	3.48	60	21.90

Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight Condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number

[1]cg range: 37.38 to 36.15 percent mean aerodynamic chord (MAC)
[2]Based on 32 samples
[3]cg range: 37.38 to 35.88 percent MAC
[4]Based on 52 samples



Notes: 1. Flight Condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number
2. cg location: 36.76 percent mean aerodynamic chord

[1]Same noise used for both cases

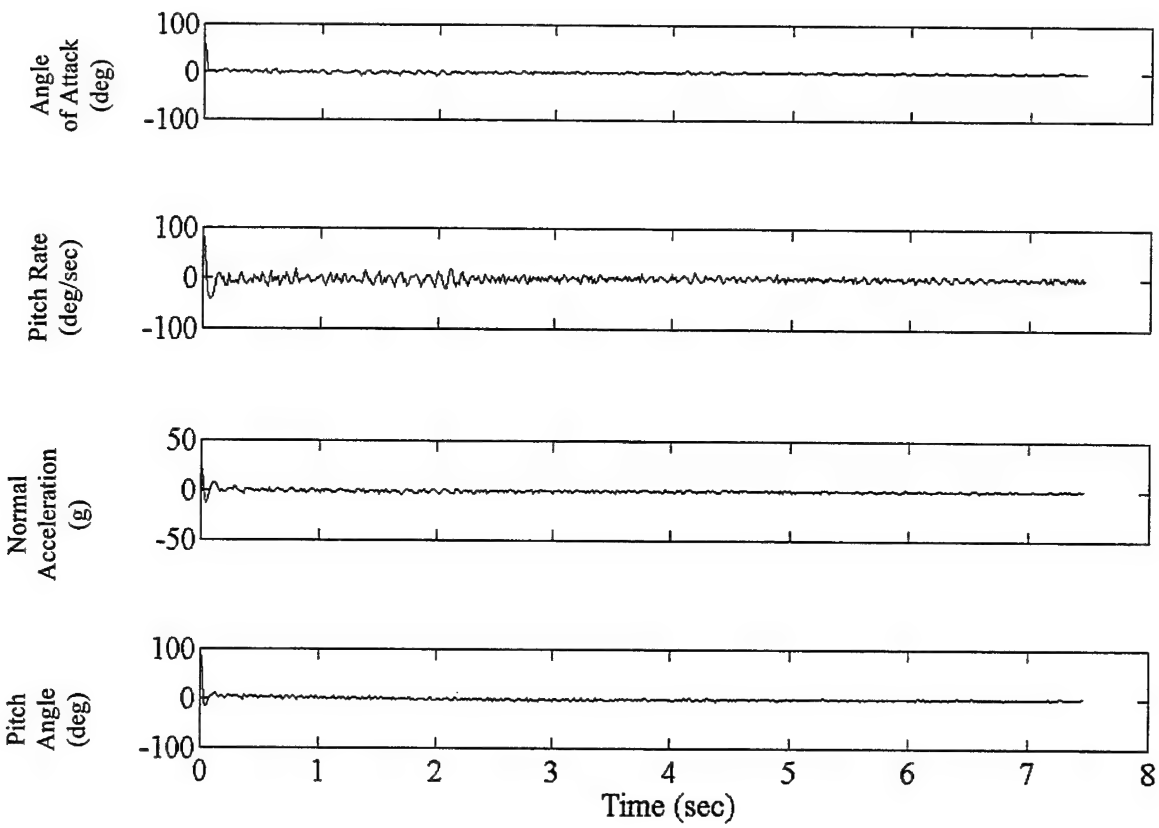
Figure 10 F-16B Noise Free and Noisy Simulated Angle-of-Attack Responses

effectiveness of the HAVE DERIVATIVES process at minimizing noise induced variance through ensemble averaging.

The simulation was accomplished with the F16_SIM program discussed earlier. The noise-free ideal impulse response was included as a reference. The same level of process and measurement noise was used for both the discrete pulse response and simulated ideal impulse response. The discrete pulse response was created by processing a broadband input and response through the HAVE DERIVATIVES process. The simulated ideal impulse response was produced by a linear simulation with the simulated ideal impulse as the input. The simulated ideal impulse response represented a typical turbulent air signal that could be given to PCPID to estimate stability derivatives. The impact of that level of turbulence was covered in the previous section. The discrete pulse response demonstrated the effectiveness of the HAVE DERIVATIVES process. The noise was minimized by the process to give a response that nearly matched the noise-free ideal impulse response.

The AOA, pitch rate, and normal acceleration discrete pulse responses from simulated noisy data were imported into PCPID along with a simulated ideal impulse input as before. The PCPID was able to match the responses well and rendered derivative results that were as good as the calm air simulation results presented in Table 8.

Unfortunately, the problems that were encountered with the calm air flight data using the HAVE DERIVATIVES process were again encountered with turbulent air flight data. Lack of uniformly distributed frequency content in the frequency sweep flight test input and higher levels of turbulence resulted in unreasonable discrete pulse responses from the HAVE DERIVATIVES process. A typical set of turbulent air discrete pulse responses are shown in Figure 11. In particular, notice the unreasonable initial values as indicated by the vertical scales which were increased by a factor of 5 to 10 over the calm air scales in Figure 8.



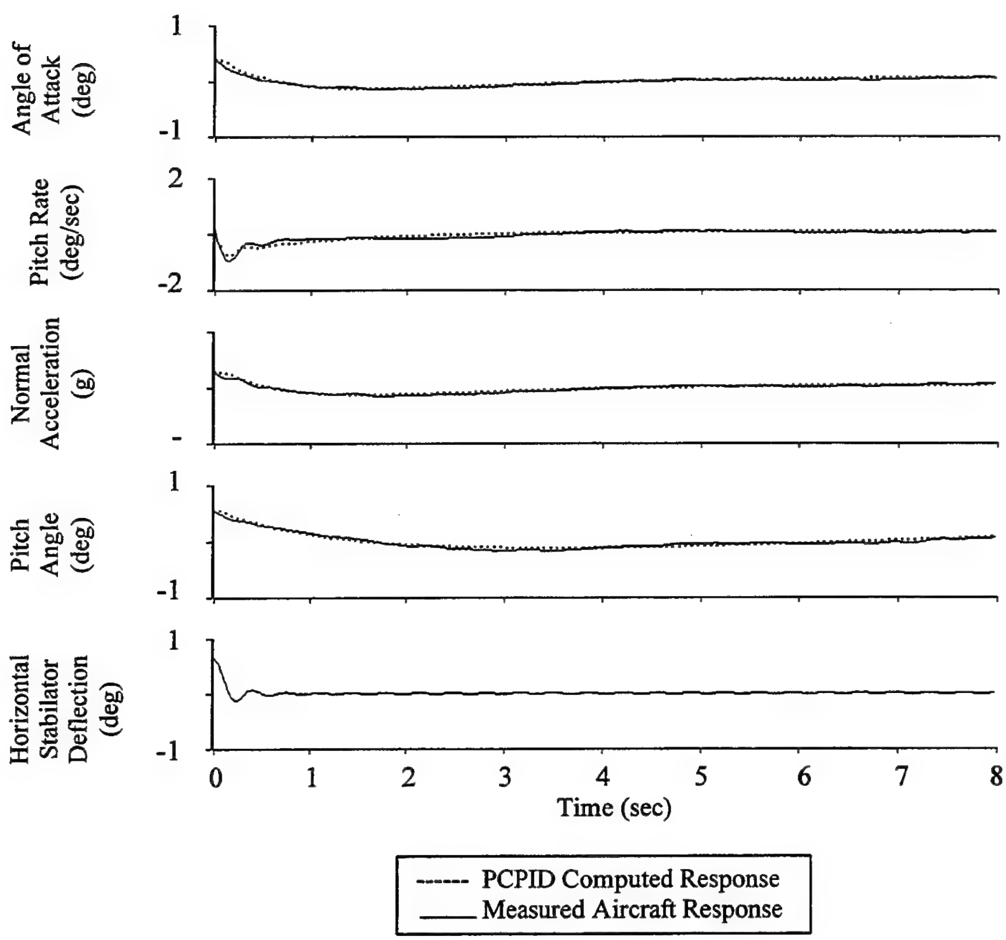
Notes: 1. Flight Condition: 4,000 ft PA, 0.65 M, Turbulent Air
2. cg location: 36.85 percent mean aerodynamic chord

Figure 11 F-16B Turbulent Air Discrete Pulse Responses From the HAVE DERIVATIVES Process

The responses in Figure 11 were imported into the PCPID along with the simulated ideal impulse input. The resulting time-history matches were practically useless as PCPID attempted to correlate the excessive initial values of the discrete pulse responses with the simulated ideal impulse input. Unreasonable stability derivative estimates were computed by PCPID in conjunction with the unsatisfactory time-history matches. Finally, excessive Cramer-Rao bounds completed the unfiltered turbulent air results using the HAVE DERIVATIVES process with PCPID.

The unsatisfactory results indicated that the HAVE DERIVATIVES process was ineffective at minimizing the noise degradation. An input with uniformly distributed frequency content could have enabled the ensemble averaging step of the process to minimize the variance as it had in simulation, giving much better turbulent air stability derivative estimation results.

The same low-pass Butterworth filters were applied to the turbulent air data, using MATLAB's® FILTFILT.M routine, as was done with the calm air data. Again, the simulated ideal impulse input was filtered independently and imported into PCPID along with the filtered discrete pulse responses. Time-history matches of the filtered turbulent air discrete pulse responses are presented in Figure 12.



Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight Condition: 4,000 feet Press Altitude, 0.65 Mach Number, Turbulent Air
3. cg location: 36.85 percent mean aerodynamic chord

Figure 12 Matches of PCPID Computed Time Histories to Filtered F-16B Turbulent Air Discrete Pulse Responses From the HAVE DERIVATIVES Process

The time-history matches in Figure 12 were satisfactory considering how degraded the signals were prior to filtering, as shown in Figure 11. As in the calm air example, the low-pass Butterworth filters were able to eliminate most of the high frequency noise. Despite the greatly increased degradation present in Figure 11, as compared to the unfiltered calm air responses in Figure 5, the filtered turbulent air responses in Figure 12 were almost identical to the filtered calm air signals in Figure 7. Those qualitative comparisons illustrated well the effectiveness of the low-pass filters.

To quantify the low-pass filter's effectiveness, comparisons are made in Table 14 between the filtered turbulent air results using the HAVE DERIVATIVES process with PCPID, the filtered calm air results using the HAVE DERIVATIVES process with PCPID, and the basis data set results.

The results presented in Table 14 were mixed. As expected, all of the filtered turbulent air HAVE DERIVATIVES Cramer-Rao bounds were larger than the filtered calm air HAVE derivatives results; however, an unexpected finding was that the filtered turbulent air HAVE DERIVATIVES results showed smaller Cramer-Rao bounds than the associated basis data set Cramer-Rao bounds for $C_{m\alpha}$, C_{mq} and $C_{m\delta e}$. Another unexpected outcome was that the filtered turbulent air HAVE DERIVATIVES estimates for C_{mq} and $C_{m\delta e}$ were closer to their basis data set mean estimates than the filtered calm air HAVE DERIVATIVES values for the same derivatives. Based on the results shown in Table 14, the low-pass filters appeared to be effective at minimizing the estimation errors due to process and measurement noises.

A final set of numerical results are presented in Table 15. Filtered turbulent air results using the HAVE DERIVATIVES process with PCPID are quantitatively compared to associated basis data set results and to turbulent air doublet results using PCPID alone.

Table 14
F-16B FILTERED RESULTS USING THE HAVE DERIVATIVES PROCESS WITH PCPID AND ASSOCIATED BASIS DATA SET RESULTS

Stability Derivative	Basis Data Set Calm Air, PCPID Alone [1,2]		Filtered, Calm Air, HAVE DERIVATIVES with PCPID[3,4]		Filtered, Turbulent Air, HAVE DERIVATIVES with PCPID[4,5]	
	Mean Estimate	Mean Cramer-Rao Bound	Estimate	Cramer-Rao Bound	Estimate	Cramer-Rao Bound
$C_{N\alpha}$ (per deg)	0.0714	±4.4e-03	0.0661	±4.2e-03	0.0639	±6.2e-03
$C_{N\delta e}$ (per deg)	0.0132	±4.8e-03	0.0182	±5.1e-03	0.0192	±8.1e-03
$C_{m\alpha}$ (per deg)	0.0008	±5.7e-04	0.0007	±1.1e-04	0.0001	±1.4e-04
C_{mq} (per rad)	-3.1380	±1.1e-00	-7.0223	±3.9e-01	-3.9577	±6.2e-01
$C_{m\delta e}$ (per deg)	-0.0114	±9.9e-04	-0.0132	±5.3e-04	-0.0104	±9.0e-04

Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach number
3. Cramer-Rao bounds have been multiplied by a factor of 10

[1]cg range: 37.38 to 36.15 percent mean aerodynamic chord (MAC)
[2]Based on 32 samples
[3]cg location: 37.03 percent MAC
[4]Based on 1 sample
[5]cg location: 36.85 percent MAC

Table 15
F-16B FILTERED TURBULENT AIR RESULTS USING THE HAVE DERIVATIVES PROCESS WITH PCPID, TURBULENT AIR DOUBLET RESULTS USING PCPID ALONE, AND ASSOCIATED BASIS DATA SET RESULTS

Stability Derivative	Basis Data Set Calm Air PCPID Alone [1,2] Mean Estimate	Mean Cramer-Rao Bound	Doublet Input, Turbulent Air, PCPID Alone[3,4] Estimate	Cramer-Rao Bound	Filtered, Turbulent Air HAVE DERIVATIVES with PCPID[3,4] Estimate	Cramer-Rao Bound
$C_{N\alpha}$ (per deg)	0.0714	±4.4e-03	0.0704	±3.9e-03	0.0639	±6.2e-03
$C_{N\delta e}$ (per deg)	0.0132	±4.8e-03	0.0179	±5.4e-03	0.0192	±8.1e-03
$C_{m\alpha}$ (per deg)	0.0008	±5.7e-04	0.0008	±3.0e-04	0.0001	±1.4e-04
C_{mq} (per rad)	-3.1380	±1.1e-00	-4.1945	±8.2e-01	-3.9577	±6.2e-01
$C_{m\delta e}$ (per deg)	-0.0114	±9.9e-04	-0.0109	±8.3e-04	-0.0104	±9.0e-04

Notes: 1. PCPID - Personal Computer Parameter Identification
2. Flight condition: 4,000 Feet Pressure Altitude, 0.65 Mach Number
3. Cramer-Rao bounds have been multiplied by a factor of 10

[1]cg range: 37.38 to 36.15 percent mean aerodynamic chord (MAC)
[2]Based on 32 samples
[3]cg location: 37.03 percent MAC
[4]Data from Flight 5, Pass 5

Again the results were mixed. While the filtered turbulent air HAVE DERIVATIVES results in Table 14 indicated significant benefit from using the low-pass filters, the turbulent air doublet results in Table 15 were better in most cases. The turbulent air doublet estimates were closer to the associated basis data set mean estimates for all derivatives except C_{mq}. In addition, the turbulent air doublet Cramer-Rao bounds were smaller than the filtered turbulent air HAVE DERIVATIVES Cramer-Rao bounds except for $C_{m\alpha}$ and C_{mq}.

While the comparisons from Table 14 appeared to indicate significant benefit from using the low-pass Butterworth filters in conjunction with the HAVE DERIVATIVES process, the comparisons based on results in Table 15 indicated that equal or better performance was achieved using the current method of processing doublet input and responses with PCPID alone.

Based on those observations, for signals used in parameter estimation, it is again recommended that low-pass filters not be used to remove noise unless absolutely necessary, and then only at a cutoff frequency high enough above the dynamics of interest so as not to corrupt those dynamics.

Overall, the best flight data results were achieved using the current method in calm air. Results using the HAVE DERIVATIVES process with PCPID should improve with a uniformly distributed frequency content input, such as the broadband input used in simulation. If flight results approach the HAVE Derivative process performance realized in simulation, the process should give better stability derivative estimation results in both calm and turbulent conditions.

TEST AND EVALUATION SUMMARY

The conclusions of the HAVE DERIVATIVES evaluation are summarized as follows:

1. The USAF TPS data reduction processes and test aircraft instrumentation were validated using results presented in AFFTC-TLR-92-12. (Reference 4)

2. A basis data set of calm air stability derivative estimation results was established with high confidence using doublet input and response signals in PCPID alone.

3. As expected, turbulent air results using doublet input and response signals with PCPID alone were consistently worse than calm air doublet results using PCPID alone.

4. The HAVE DERIVATIVES process was validated with an F-16B simulation model, achieving excellent results similar to earlier AT-37B simulations.

5. Calm and turbulent air results using the HAVE DERIVATIVES process with PCPID were unacceptable due to high frequency noise on the discrete pulse responses.

6. Due to the nonuniform frequency content of the frequency sweep flight test input, the ensemble averaging step of the HAVE DERIVATIVES process was not effective enough at minimizing signal noise.

7. Low-pass Butterworth filters applied forward and reverse in time were very effective at minimizing high frequency signal noise while inducing zero phase error.

8. Low-pass filters applied to the response signals before HAVE DERIVATIVES processing, and independently to a simulated ideal impulse input signal, resulted in smaller Cramer-Rao bounds when incorporated into the HAVE DERIVATIVES process
with PCPID.

9. Variable amplitude attenuation caused by the low-pass filters resulted in unacceptable estimate accuracy.

CONCLUSIONS AND RECOMMENDATION

A flight test program was conducted to evaluate the HAVE DERIVATIVES data reduction process. Following is a list of the conclusions and recommendation of this evaluation:

1. The USAF TPS data reduction processes and test aircraft instrumentation were validated against results presented in the Air Force Flight Test Center's (AFFTCs) technical letter report (TLR) titled, *F-16B Parameter Estimation (PEST)*, AFFTC-TLR-92-12.

2. A flight test basis data set of calm air stability derivative estimation results was established with high confidence using doublet input and response signals in PCPID alone.

3. As expected, turbulent air results using doublet input and response signals with PCPID alone were consistently worse than calm air doublet results using PCPID alone.

4. The HAVE DERIVATIVES process was validated with an F-16B simulation model, achieving excellent results.

5. Calm and turbulent air results using the HAVE DERIVATIVES process with PCPID were unacceptable due to high-frequency noise on the discrete pulse responses.

6. Due to the nonuniform frequency content of the frequency sweep flight test input, the ensemble averaging step of the HAVE DERIVATIVES process was not effective enough at minimizing signal noise.

> **1. *The HAVE DERIVATIVES process should be evaluated using a broadband programmed test input in flight. (Page 15)***

7. Low-pass Butterworth filters, applied forward and reverse in time, were very effective at minimizing high frequency signal noise while inducing zero-phase error.

8. Low-pass filters applied to the response signals before HAVE DERIVATIVES processing, and independently to a simulated ideal impulse input signal, resulted in smaller Cramer-Rao bounds when incorporated into the HAVE DERIVATIVES process with PCPID.

9. Variable amplitude attenuation caused by the low-pass filters resulted in unacceptable estimate accuracy.

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APPENDIX A

STABILITY DERIVATIVE ESTIMATE RESULTS

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STABILITY DERIVATIVE ESTIMATE RESULTS

This appendix presents the stability derivative estimates and associated Cramer-Rao bounds for $C_{N\alpha}$, $C_{N\delta e}$, $C_{m\alpha}$, C_{mq}, and $C_{m\delta e}$ calculated using the Personal Computer Parameter Identification (PCPID) alone and using the HAVE DERIVATIVES process with PCPID. The Cramer-Rao bound was a measure of the confidence PCPID had in each stability derivative estimate. The smaller the Cramer-Rao bound, the more confidence PCPID had in the estimate. The Cramer-Rao bound values presented throughout this report were the actual bound multiplied by a factor of 10. This factor has been commonly used at the Air Force Flight Test Center, Edwards AFB, California, to account for the fact that the true noise present on the signals processed by PCPID is correlated, not uncorrelated as assumed by the parameter estimation routine in PCPID, and to more closely correlate the size of the bounds to the scatter of the estimates (Reference 1).

The turbulence level definitions used to categorize results are presented in Table A1. The data are divided into two tables. Table A2 presents the calm air stability derivative estimates using PCPID alone. Table A3 presents the turbulent air stability derivative estimates using PCPID alone.

The mean stability derivative estimate values and associated confidence intervals (CI), as well as the standard deviations and associated lower confidence bounds (LCB) and upper confidence bounds (UCB), based on a 95-percent confidence level, are presented at the top Tables A2 and A3.

The 95-percent confidence level intervals was calculated using the following equation:

$$\mu = \bar{x} \pm t_{\upsilon,1-\frac{\alpha}{2}}\left(\frac{s}{\sqrt{n}}\right)$$

where:

μ = population mean

$\bar{x}$ = sample mean

$t_{\upsilon,1-\frac{\alpha}{2}}$ = Student's t distribution statistic

υ = degrees of freedom (n - 1)

α = uncertainty level (0.05 for 95 - percent confidence level)

s = sample standard deviation

n = number of samples

Table A1
TURBULENCE LEVEL DEFINITIONS

Turbulence Level	ΔNormal Acceleration (Δg)[1]
Calm Air	$\lvert \Delta n_z \rvert \leq 0.1$
Turbulent Air	$0.3 \leq \lvert \Delta n_z \rvert$

Notes: 1. Δ - increment of change
2. g – acceleration due to gravity
3. n_z - normal acceleration

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second.

Table A2
CALM AIR STABILITY DERIVATIVE ESTIMATE RESULTS USING PCPID ALONE

					$C_{N\alpha}$	CR bnd[9]	$C_{N\delta e}$	CR bnd	$C_{m\alpha}$	CR bnd	C_{mq}	CR bnd	$C_{m\delta e}$	CR bnd
Mean[4]					0.0714	4.38E-03	0.0132	4.76E-03	0.0008	5.70E-04	-3.1380	1.10E+00	-0.0114	9.90E-04
Mean CI[5]					0.0009	6.63E-04	0.0007	5.21E-04	0.0005	1.51E-04	0.5339	2.22E-01	0.0008	2.07E-04
Desired Confidence Interval					2.5E-03		2.0E-03		2.5E-04		4.0E-01		4.0E-04	
Confidence Level[6]					1.0000		1.0000		0.6606		0.8634		0.7056	
Standard Deviation					0.0025	1.84E-03	0.0019	1.45E-03	0.0015	4.20E-04	1.4808	6.15E-01	0.0021	5.74E-04
Std Dev LCB[7]					0.0020	1.53E-03	0.0016	1.20E-03	0.0012	3.48E-04	1.2292	5.11E-01	0.0018	4.77E-04
Std Dev UCB[8]					0.0031	2.33E-03	0.0024	1.83E-03	0.0018	5.32E-04	1.8776	7.80E-01	0.0027	7.28E-04
Flt	Pass	X-cg[1] (ft)	X-cg[2] (pct)	Avg α[3]	$C_{N\alpha}$	CR bnd	$C_{N\delta e}$	CR bnd	$C_{m\alpha}$	CR bnd	C_{mq}	CR bnd	$C_{m\delta e}$	CR bnd
1	5	0.20	36.76	2.11	0.0708	5.24E-03	0.0133	4.35E-03	0.0000	5.77E-04	-4.4123	1.43E+00	-0.0103	9.46E-04
1	6	0.17	36.50	2.08	0.0681	4.27E-03	0.0153	3.77E-03	0.0004	3.42E-04	-5.5375	1.18E+00	-0.0110	7.63E-04
1	7	0.18	36.59	1.98	0.0729	4.14E-03	0.0132	3.65E-03	-0.0002	9.09E-04	-4.6108	1.92E+00	-0.0105	1.14E-03
1	8	0.20	36.76	2.00	0.0623	4.76E-03	0.0152	4.92E-03	0.0001	5.64E-04	-4.5818	1.77E+00	-0.0106	1.09E-03
2	1	0.27	37.38	2.38	0.0686	5.52E-03	0.0141	5.03E-03	0.0013	3.87E-04	-1.4549	7.87E-01	-0.0114	8.26E-04
2	2	0.27	37.38	2.23	0.0715	3.70E-03	0.0126	3.83E-03	0.0025	6.11E-04	-4.7675	1.13E+00	-0.0134	9.82E-04
2	3	0.27	37.38	1.94	0.0732	5.08E-03	0.0131	5.08E-03	0.0045	9.48E-04	-5.7164	1.59E+00	-0.0151	1.39E-03
2	4	0.25	37.21	2.13	0.0710	4.08E-03	0.0129	4.30E-03	0.0028	6.87E-04	-4.5500	1.28E+00	-0.0138	1.08E-03
2	5	0.22	36.94	2.09	0.0716	4.60E-03	0.0124	5.27E-03	0.0020	5.52E-04	-2.3454	9.61E-01	-0.0131	1.01E-03
2	6	0.19	36.68	1.98	0.0729	5.33E-03	0.0116	5.03E-03	0.0025	7.67E-04	-3.3342	1.27E+00	-0.0133	1.23E-03
2	7	0.17	36.50	1.84	0.0753	6.84E-03	0.0094	7.04E-03	0.0031	1.40E-03	-4.0800	2.13E+00	-0.0139	1.99E-03
2	8	0.18	36.59	1.89	0.0728	5.93E-03	0.0122	6.16E-03	0.0018	9.42E-04	-2.8480	1.53E+00	-0.0129	1.54E-03
2	9	0.19	36.68	1.87	0.0672	1.16E-02	0.0154	1.07E-02	-0.0008	1.76E-03	-1.1682	2.30E+00	-0.0094	2.86E-03
2	10	0.20	36.76	1.84	0.0744	4.77E-03	0.0107	4.12E-03	0.0020	8.96E-04	-4.0223	1.46E+00	-0.0135	1.23E-03
2	11	0.22	36.94	1.92	0.0743	4.56E-03	0.0093	6.23E-03	0.0021	8.75E-04	-4.7754	1.69E+00	-0.0150	1.61E-03
2	12	0.24	37.12	1.93	0.0717	5.90E-03	0.0123	5.32E-03	0.0003	8.29E-04	-1.8626	1.30E+00	-0.0117	1.33E-03
2	13	0.21	36.85	1.99	0.0714	4.71E-03	0.0137	4.46E-03	0.0003	6.91E-04	-2.8059	1.21E+00	-0.0122	1.22E-03
2	14	0.19	36.68	1.76	0.0741	5.76E-03	0.0104	5.63E-03	0.0012	7.31E-04	-2.6277	1.29E+00	-0.0129	1.32E-03
2	15	0.16	36.41	1.70	0.0717	5.60E-03	0.0140	5.66E-03	0.0023	1.22E-03	-5.0852	2.31E+00	-0.0147	1.80E-03
3	1	0.27	37.38	2.53	0.0696	4.28E-03	0.0137	4.38E-03	0.0026	6.97E-04	-4.8283	1.36E+00	-0.0134	1.07E-03
3	2	0.27	37.38	2.11	0.0710	2.96E-03	0.0149	3.92E-03	-0.0001	1.61E-04	-2.3739	4.17E-01	-0.0095	4.23E-04
3	4	0.23	37.03	2.10	0.0701	2.95E-03	0.0153	3.73E-03	0.0001	2.10E-04	-3.6422	5.57E-01	-0.0098	5.23E-04
3	5	0.20	36.76	1.98	0.0698	2.36E-03	0.0156	2.99E-03	-0.0006	1.42E-04	-1.8586	3.71E-01	-0.0092	3.55E-04
3	6	0.17	36.50	1.86	0.0729	3.36E-03	0.0119	3.82E-03	-0.0010	1.94E-04	-1.4672	4.48E-01	-0.0092	4.51E-04
3	7	0.18	36.59	2.02	0.0706	2.49E-03	0.0154	3.32E-03	-0.0005	1.45E-04	-2.4108	4.04E-01	-0.0096	3.92E-04
3	8	0.19	36.68	1.72	0.0716	3.41E-03	0.0126	3.92E-03	-0.0009	1.86E-04	-1.6525	4.24E-01	-0.0096	4.56E-04
3	9	0.21	36.85	1.76	0.0730	3.60E-03	0.0105	4.25E-03	-0.0012	1.51E-04	-0.7620	4.11E-01	-0.0088	4.27E-04
3	11	0.24	37.12	1.67	0.0721	2.12E-03	0.0127	3.15E-03	-0.0006	1.08E-04	-1.9607	3.22E-01	-0.0092	3.42E-04
3	12	0.21	36.85	1.70	0.0712	2.99E-03	0.0156	5.87E-03	-0.0008	1.11E-04	-0.3922	3.76E-01	-0.0079	3.99E-04
3	13	0.19	36.68	1.64	0.0714	2.38E-03	0.0156	3.92E-03	-0.0002	1.44E-04	-2.0307	4.60E-01	-0.0090	4.22E-04
3	14	0.16	36.41	1.47	0.0733	2.52E-03	0.0129	4.16E-03	0.0000	1.40E-04	-2.6051	5.02E-01	-0.0089	4.75E-04
3	15	0.13	36.15	1.51	0.0729	2.19E-03	0.0150	4.43E-03	0.0003	1.66E-04	-3.8444	5.78E-01	-0.0105	5.99E-04

Notes:
1. Flt - Flight number
2. Pass - Pass number during flight
3. PCPID - Personal Computer Parameter Identification

[1]X-cg location measured from a reference point 320.65 inches (35 percent of mean aerodynamic chord [MAC]) aft of fuselage station 0.0
[2]X-cg location measured in percent of MAC
[3]Average angle of attack for pass
[4]Mean based on 32 samples
[5]Confidence interval (CI) of the mean based on a 95-percent confidence level
[6]Confidence level based on desired confidence interval
[7]Standard deviation lower confidence bound (LCB) based on a 95-percent confidence level
[8]Standard deviation upper confidence bound (UCB) based on a 95-percent confidence level
[9]Cramer-Rao (CR) bounds (bnd) have been multiplied by a factor of 10

Table A3
TURBULENT AIR STABILITY DERIVATIVE ESTIMATE RESULTS USING PCPID ALONE

					$C_{N\alpha}$	CR bnd[9]	$C_{N\delta_e}$	CR bnd	$C_{m\alpha}$	CR bnd	C_{mq}	CR bnd	$C_{m\delta_e}$	CR bnd
Mean[4]					0.0693	6.49E-03	0.0174	8.63E-03	0.0010	8.03E-04	-3.5564	1.89E+00	-0.0111	1.61E-03
Mean CI[5]					1.67E-03	5.89E-04	2.26E-03	9.06E-04	3.99E-04	1.49E-04	7.91E-01	3.13E-01	7.80E-04	2.20E-04
Desired Confidence Interval					2.50E-03		2.00E-03		2.50E-04		4.00E-01		4.00E-04	
Confidence Level[6]					99.6%		91.9%		78.6%		68.5%		69.2%	
Standard Deviation					0.0060	2.12E-03	0.0081	3.25E-03	0.0014	5.34E-04	2.8403	1.12E+00	0.0028	7.90E-04
Std Dev LCB[7]					0.0052	1.82E-03	0.0070	2.80E-03	0.0012	4.60E-04	2.4478	9.69E-01	0.0024	6.81E-04
Std Dev UCB[8]					0.0073	2.53E-03	0.0097	3.89E-03	0.0017	6.39E-04	3.3996	1.35E+00	0.0034	9.46E-04
Flt	Pass	X-cg[1] (ft)	X-cg[2] (pct)	Avg α[3]	$C_{N\alpha}$	CR bnd	$C_{N\delta_e}$	CR bnd	$C_{m\alpha}$	CR bnd	C_{mq}	CR bnd	$C_{m\delta_e}$	CR bnd
4	4	0.24	37.12	1.93	0.0709	7.54E-03	0.0084	8.18E-03	0.0021	1.36E-03	-4.3194	2.66E+00	-0.0116	2.03E-03
4	6	0.18	36.59	1.96	0.0628	6.26E-03	0.0217	8.51E-03	-0.0013	1.67E-04	1.6780	5.49E-01	-0.0066	5.81E-04
4	7	0.17	36.50	1.67	0.0697	9.24E-03	0.0088	9.03E-03	0.0014	1.94E-03	-1.3382	2.66E+00	-0.0117	2.56E-03
4	8	0.18	36.59	1.91	0.0714	5.57E-03	0.0117	4.46E-03	0.0020	8.69E-04	-3.9896	1.59E+00	-0.0125	1.16E-03
4	10	0.21	36.85	1.72	0.0828	8.95E-03	0.0046	7.21E-03	0.0008	1.11E-03	-3.8905	2.22E+00	-0.0122	1.71E-03
4	16	0.15	36.32	1.71	0.0749	4.78E-03	0.0114	4.88E-03	0.0024	8.83E-04	-6.3715	1.80E+00	-0.0148	1.46E-03
4	17	0.13	36.15	1.60	0.0752	5.74E-03	0.0100	5.78E-03	0.0021	9.29E-04	-5.2690	1.71E+00	-0.0146	1.54E-03
4	18	0.10	35.88	1.39	0.0756	6.01E-03	0.0097	4.93E-03	0.0024	7.83E-04	-5.3536	1.52E+00	-0.0145	1.34E-03
5	1	0.26	37.29	2.15	0.0723	4.40E-03	0.0063	6.94E-03	-0.0002	3.50E-04	-1.3737	7.18E-01	-0.0089	8.95E-04
5	2	0.27	37.38	1.95	0.0705	7.77E-03	0.0168	1.28E-02	-0.0009	2.62E-04	0.8676	7.35E-01	-0.0070	8.05E-04
5	3	0.27	37.38	2.29	0.0616	5.88E-03	0.0259	9.65E-03	0.0010	5.97E-04	-3.8764	1.50E+00	-0.0102	1.51E-03
5	4	0.25	37.21	1.88	0.0690	5.83E-03	0.0237	9.36E-03	0.0004	3.75E-04	-1.9526	1.08E+00	-0.0096	1.20E-03
5	5	0.21	36.85	2.08	0.0704	3.89E-03	0.0179	5.42E-03	0.0008	2.98E-04	-4.1945	8.15E-01	-0.0109	8.33E-04
5	6	0.18	36.59	1.95	0.0632	6.46E-03	0.0209	8.83E-03	-0.0011	2.13E-04	1.5411	5.77E-01	-0.0071	7.12E-04
5	7	0.18	36.59	1.96	0.0647	5.92E-03	0.0179	8.14E-03	-0.0011	1.87E-04	1.1611	5.60E-01	-0.0072	6.41E-04
5	9	0.21	36.85	1.56	0.0654	4.90E-03	0.0215	7.32E-03	-0.0005	2.33E-04	-1.3774	7.76E-01	-0.0074	7.51E-04
5	11	0.24	37.12	1.73	0.0678	5.16E-03	0.0116	6.69E-03	-0.0006	2.12E-04	-2.6699	8.36E-01	-0.0080	7.00E-04
5	12	0.22	36.94	1.82	0.0690	4.52E-03	0.0192	5.83E-03	-0.0008	2.70E-04	-1.0655	6.37E-01	-0.0091	7.79E-04
5	13	0.20	36.76	1.57	0.0722	5.80E-03	0.0167	1.01E-02	-0.0005	1.90E-04	0.3229	6.58E-01	-0.0082	7.71E-04
6	6	0.18	36.59	2.24	0.0735	3.60E-03	0.0103	6.78E-03	0.0013	1.43E-03	-4.7636	2.84E+00	-0.0134	2.71E-03
6	7	0.17	36.50	2.43	0.0704	5.44E-03	0.0184	9.85E-03	0.0015	5.37E-04	-3.2032	1.23E+00	-0.0139	1.55E-03
6	8	0.19	36.68	1.60	0.0735	3.76E-03	0.0157	6.32E-03	0.0031	6.10E-04	-8.1452	1.55E+00	-0.0161	1.42E-03
6	10	0.21	36.85	1.97	0.0731	5.03E-03	0.0110	8.26E-03	0.0017	9.14E-04	-4.8711	1.90E+00	-0.0143	2.11E-03
6	12	0.23	37.03	1.51	0.0696	4.87E-03	0.0170	9.77E-03	0.0022	7.64E-04	-6.8179	2.23E+00	-0.0140	1.88E-03
6	14	0.20	36.76	1.45	0.0713	4.59E-03	0.0143	5.81E-03	0.0035	1.40E-03	-7.0112	2.45E+00	-0.0156	2.13E-03
8	6	0.26	37.29	2.06	0.0724	4.68E-03	0.0107	4.86E-03	0.0035	8.43E-04	-7.4791	1.41E+00	-0.0145	1.29E-03
8	10	0.27	37.38	1.94	0.0670	3.51E-03	0.0175	3.93E-03	0.0027	5.54E-04	-5.0190	9.46E-01	-0.0137	9.20E-04
8	11	0.25	37.21	2.07	0.0698	5.77E-03	0.0154	6.97E-03	0.0028	9.07E-04	-4.5197	1.44E+00	-0.0143	1.60E-03
8	14	0.18	36.59	1.78	0.0683	6.24E-03	0.0155	6.45E-03	0.0022	1.10E-03	-7.0042	2.33E+00	-0.0132	1.61E-03
8	17	0.19	36.68	1.55	0.0754	5.63E-03	0.0107	5.69E-03	0.0011	7.99E-04	-4.6725	1.63E+00	-0.0120	1.31E-03
8	19	0.21	36.85	1.86	0.0473	1.04E-02	0.0432	1.12E-02	0.0041	2.41E-03	-2.1807	2.51E+00	-0.0165	3.49E-03
8	20	0.22	36.94	1.68	0.0722	5.97E-03	0.0133	6.51E-03	0.0016	8.41E-04	-4.1524	1.43E+00	-0.0131	1.46E-03
8	21	0.23	37.03	1.41	0.0665	1.01E-02	0.0112	9.94E-03	0.0024	1.51E-03	-6.8145	3.20E+00	-0.0114	2.46E-03
8	23	0.21	36.85	1.37	0.0783	6.43E-03	0.0078	5.73E-03	0.0016	7.45E-04	-4.8968	1.38E+00	-0.0122	1.29E-03
9	1	0.27	37.38	1.97	0.0677	6.99E-03	0.0250	1.04E-02	0.0037	1.75E-03	-7.5557	3.89E+00	-0.0147	3.10E-03
9	3	0.22	36.94	2.14	0.0695	3.55E-03	0.0179	4.15E-03	0.0003	3.58E-04	-4.0784	8.71E-01	-0.0106	8.26E-04
9	4	0.17	36.50	2.54	0.0670	5.69E-03	0.0189	7.67E-03	0.0005	6.28E-04	-4.7841	1.81E+00	-0.0109	1.44E-03
9	5	0.17	36.50	2.12	0.0851	7.81E-03	0.0097	8.21E-03	0.0013	9.77E-04	-7.8236	2.76E+00	-0.0125	2.14E-03
9	7	0.20	36.76	2.04	0.0593	9.43E-03	0.0252	1.53E-02	0.0002	5.28E-04	-3.4505	2.40E+00	-0.0111	1.90E-03
9	8	0.22	36.94	1.98	0.0686	7.04E-03	0.0158	8.78E-03	-0.0010	6.96E-04	0.2452	1.72E+00	-0.0090	1.77E-03
9	9	0.22	36.94	1.81	0.0753	1.07E-02	0.0131	1.14E-02	-0.0007	2.03E-03	-2.7086	3.99E+00	-0.0089	3.33E-03
9	10	0.24	37.12	1.90	0.0619	8.25E-03	0.0363	1.42E-02	0.0009	1.82E-03	-4.5366	5.49E+00	-0.0111	4.01E-03
9	11	0.23	37.03	1.65	0.0730	7.42E-03	0.0074	1.08E-02	-0.0005	6.96E-04	-1.1400	1.84E+00	-0.0080	1.74E-03
9	12	0.20	36.76	1.65	0.0659	6.24E-03	0.0184	7.80E-03	0.0000	6.78E-04	-2.9718	2.21E+00	-0.0091	1.52E-03
9	13	0.18	36.59	1.74	0.0736	1.07E-02	0.0096	9.96E-03	0.0020	1.56E-03	-11.0785	5.80E+00	-0.0112	3.27E-03
9	15	0.14	36.23	1.78	0.0600	5.41E-03	0.0326	8.38E-03	0.0005	5.03E-04	-4.4206	1.77E+00	-0.0104	1.60E-03
9	16	0.13	36.15	1.73	0.0620	6.71E-03	0.0310	1.02E-02	0.0003	7.25E-04	-4.0661	2.58E+00	-0.0096	1.94E-03
10	3	0.21	36.85	2.44	0.0673	7.15E-03	0.0257	1.40E-02	-0.0002	2.62E-04	0.5221	1.16E+00	-0.0078	1.01E-03
10	5	0.17	36.50	2.15	0.0675	6.59E-03	0.0201	1.34E-02	0.0002	4.02E-04	-2.9807	1.79E+00	-0.0093	1.26E-03
10	7	0.19	36.68	2.09	0.0681	4.13E-03	0.0229	8.14E-03	-0.0001	3.37E-04	-1.3016	1.17E+00	-0.0075	8.67E-04
10	12	0.20	36.76	1.60	0.0708	1.14E-02	0.0243	2.12E-02	-0.0003	4.61E-04	1.4674	1.89E+00	-0.0067	1.53E-03
10	13	0.17	36.50	1.85	0.0656	1.18E-02	0.0325	1.26E-02	-0.0006	7.49E-04	-1.2483	2.89E+00	-0.0073	1.55E-03

Notes:
1. Flt - Flight number
2. Pass - Pass number during flight
3. PCPID - Personal Computer Parameter Identification

[1] X-cg location measured from a reference point 320.65 inches (35 percent of mean aerodynamic chord [MAC]) aft of fuselage station 0.0
[2] X-cg location measured in percent of MAC
[3] Average angle of attack during pass
[4] Mean based on 52 samples
[5] Confidence interval (CI) of the mean based on a 95-percent confidence level
[6] Confidence level based on desired confidence interval
[7] Standard deviation lower confidence bound (LCB) based on a 95-percent confidence level
[8] Standard deviation upper confidence bound (UCB) based on a 95-percent confidence level
[9] Cramer-Rao (CR) bounds (bnd) have been multiplied by a factor of 10

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APPENDIX B

TIME-HISTORY MATCH COST FUNCTION VALUES

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TIME-HISTORY MATCH COST FUNCTION VALUES

This appendix presents cost function values associated with the time-history matches calculated using Personal Computer Parameter Identification (PCPID) alone. The cost function values were a quantitative indication of how closely the PCPID computed time histories matched the measured time histories of angle of attack (α), pitch rate (q), pitch angle(θ) and normal acceleration (n_z). The computed time histories were calculated by PCPID during each iteration of a parameter estimation pass using current estimates for $C_{N\alpha}$, $C_{N\delta e}$, $C_{m\alpha}$, C_{mq}, and $C_{m\delta e}$. Smaller cost function values indicated a closer match of the computed time histories to the measured time histories. Consequently, the derivative estimates for a pass with smaller cost function values were considered more accurate than those estimates associated with larger cost function values.

Turbulence level definitions used to categorize the results are presented in Table B1. The data are divided into two tables. Table B2 presents the calm air time history match cost functions using PCPID alone. Table B3 presents the turbulent air time history match cost functions using PCPID alone. cost function values using PCPID alone, and the HAVE DERIVATIVES process with PCPID.

Table B1
TURBULENCE LEVEL DEFINITIONS

Turbulence Level	ΔNormal Acceleration (Δg)[1]
Calm Air	$\lvert \Delta n_z \rvert \leq 0.1$
Turbulent Air	$0.3 \leq \lvert \Delta n_z \rvert$

Notes: 1. Δ - increment of change
2. g - acceleration due to gravity
3. n_z – normal acceleration

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

The means and associated confidence intervals (CI) as well as the standard deviations and the associated upper confidence bounds (UCB) and lower confidence bounds (LCB), based on a 95-percent confidence level, are presented at the top Tables B2 and B3.

Table B2
CALM AIR TIME-HISTORY MATCH COST FUNCTION VALUES USING PCPID ALONE

		Cost α[5]	Cost q[6]	Cost θ[7]	Cost n_z[8]
	Mean[1]	3.24	2.11	1.85	3.48
	Mean CI[2]	1.32	0.54	0.48	1.57
	Standard Deviation	3.66	1.50	1.32	4.35
	Std Dev LCB[3]	3.04	1.25	1.10	3.61
	Std Dev UCB[4]	4.65	1.91	1.68	5.51
Flt	Pass	Cost α	Cost q	Cost θ	Cost n_z
1	5	8.33	1.53	2.01	6.26
1	6	2.54	1.63	0.71	2.55
1	7	3.67	1.30	0.78	3.56
1	8	5.73	2.94	1.36	8.07
2	1	3.06	2.28	2.47	2.87
2	2	1.16	1.66	1.31	1.41
2	3	1.47	3.20	2.16	0.97
2	4	1.87	0.40	1.51	1.23
2	5	1.51	1.84	1.87	0.63
2	6	1.68	2.37	1.45	1.15
2	7	3.09	4.30	1.86	3.02
2	8	1.95	4.02	1.58	1.69
2	9	21.60	8.60	6.86	24.60
2	10	1.29	1.17	1.20	1.00
2	11	1.98	1.11	1.36	1.60
2	12	2.44	2.70	1.94	2.72
2	13	1.79	1.16	0.80	1.79
2	14	3.06	2.99	1.77	2.02
2	15	3.74	0.60	1.67	2.00
3	1	2.19	1.23	2.51	1.85
3	2	2.08	1.57	1.00	3.67
3	4	2.70	2.24	0.52	2.24
3	5	1.19	1.81	1.69	1.53
3	6	2.47	1.67	2.68	4.27
3	7	1.78	1.58	1.08	1.45
3	8	3.33	1.66	4.40	4.89
3	9	4.01	1.69	3.71	6.75
3	11	1.37	1.19	0.76	1.82
3	12	4.86	3.23	3.95	8.25
3	13	1.83	1.26	0.84	1.72
3	14	2.15	1.80	0.76	2.46
3	15	1.90	0.69	0.67	1.45

Notes: 1. Flt - flight number
2. Pass - pass number during flight
3. PCPID - Personal Computer Parameter Identification

[1]Mean based on 32 samples
[2]Confidence interval (CI) of the mean based on a 95-percent confidence level
[3]Standard deviation lower confidence bound (LCB) based on a 95-percent confidence level
[4]Standard deviation upper confidence bound (UCB) based on a 95-percent confidence level
[5]Cost function value associated with matching angle of attack (α) measured time history
[6]Cost function value associated with matching pitch rate (q) measured time history
[7]Cost function value associated with matching pitch angle (θ) measured time history
[8]Cost function value associated with matching normal acceleration (n_z) measured time history

Table B3
TURBULENT AIR TIME-HISTORY MATCH COST FUNCTION VALUES USING PCPID ALONE

		Cost α[5]	Cost q[6]	Cost θ[7]	Cost n_z[8]
	Mean[1]	16.88	4.49	5.82	21.90
	Mean CI[2]	4.14	0.78	1.47	4.79
	Standard Deviation	14.87	2.82	5.29	17.22
	Std Dev LCB[3]	12.82	2.43	4.56	14.84
	Std Dev UCB[4]	17.80	3.37	6.33	20.61
Flt[1]	Pass[2]	Cost α	Cost q	Cost θ	Cost n_z
4	4	17.60	4.54	5.45	27.50
4	6	21.10	7.25	17.80	35.30
4	7	9.65	4.47	10.70	19.40
4	8	3.64	6.37	3.03	5.61
4	10	10.00	2.18	7.39	11.90
4	16	4.81	2.82	3.52	9.26
4	17	5.90	4.67	6.30	7.29
4	18	4.32	3.94	3.77	8.88
5	1	9.37	4.16	2.10	7.83
5	2	32.70	5.55	13.80	54.30
5	3	22.50	10.20	5.38	31.00
5	4	35.50	5.00	6.58	45.80
5	5	5.88	3.53	6.37	9.87
5	6	21.20	6.03	18.60	37.30
5	7	18.50	5.84	14.50	31.10
5	9	13.70	4.80	2.69	14.90
5	11	16.30	1.89	4.60	18.60
5	12	17.10	3.29	6.24	23.70
5	13	9.91	6.04	2.56	17.10
6	6	3.85	3.12	1.82	8.04
6	7	5.20	2.39	2.91	6.59
6	8	5.14	0.93	2.14	7.84
6	10	6.23	9.35	2.21	10.00
6	12	20.30	2.64	4.53	17.60
6	14	4.49	1.96	3.97	5.26
8	6	4.38	2.30	2.76	7.50
8	10	3.30	1.34	4.15	2.47
8	11	8.84	1.39	3.54	8.36
8	14	9.92	1.68	3.32	15.80
8	17	4.72	1.56	4.81	6.57
8	19	15.70	8.80	20.30	27.80
8	20	9.10	2.03	3.52	11.30
8	21	21.60	2.54	5.25	35.80
8	23	3.43	4.35	2.77	9.58
9	1	12.50	4.97	3.19	19.00
9	3	8.13	3.21	0.90	7.16
9	4	15.80	2.49	1.79	26.00
9	5	17.00	5.11	1.39	21.70
9	7	64.60	12.80	10.60	58.50
9	8	13.00	1.14	1.56	16.30
9	9	23.60	7.66	3.45	34.10
9	10	33.40	6.69	1.70	41.90
9	11	9.71	2.05	1.28	13.70
9	12	10.50	3.11	1.41	12.90
9	13	19.70	6.12	6.73	31.10
9	15	19.20	2.32	2.13	24.50
9	16	28.70	6.87	2.83	19.60
10	3	50.20	11.40	18.30	34.60
10	5	24.30	2.61	3.86	24.60
10	7	5.80	1.48	1.05	5.08
10	12	41.80	4.49	12.00	62.30
10	13	73.70	10.00	19.20	88.70

Notes:
1. Flt - flight number
2. Pass - pass number during flight
3. PCPID - Personal Computer Parameter Identification

[1]Mean based on 52 samples
[2]Confidence interval (CI) of the mean based on a 95-percent confidence level
[3]Standard deviation lower confidence bound (LCB) based on a 95-percent confidence level
[4]Standard deviation upper confidence bound (UCB) based on a 95-percent confidence level
[5]Cost function value associated with matching angle of attack (α) measured time history
[6]Cost function value associated with matching pitch rate (q) measured time history
[7]Cost function value associated with matching pitch angle (θ) measured time history
[8]Cost function value associated with matching normal acceleration (n_z) measured time history

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APPENDIX C

TURBULENCE LEVELS

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TURBULENCE LEVEL

This appendix presents the turbulence level for each of the passes. Delta gravity (Δg) refers to the change in normal acceleration from 1 g encountered by the test aircraft at a frequency of 1 radian per second, approximately the test aircraft short period undamped natural frequency. The turbulence level classifications were based on the definitions given in Table C1 and the data is presented in Tables C2 through C12.

Table C1
TURBULENCE LEVEL DEFINITIONS

Turbulence Level	ΔNormal Acceleration (Δg)[1]
Calm Air	$\lvert \Delta n_z \rvert \leq 0.1$
Turbulent Air	$0.3 \leq \lvert \Delta n_z \rvert$

Notes: 1. Δ - increment of change
2. n_z - normal acceleration
3. g - acceleration due to gravity

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C2
FLIGHT 1 TURBULENCE LEVELS

Flight	Pass[1]	Δg^2	Turbulence Level
1	1	0.03	CALM
1	2	0.06	CALM
1	3	0.05	CALM
1	4	0.02	CALM
1	5	0.07	CALM
1	6	0.01	CALM
1	7	0.08	CALM
1	8	0.09	CALM

Note: Δg – delta force

[1]Flight 1, passes 1 through 4 were used to validate test instrumentation and processes
[2]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C3
FLIGHT 2 TURBULENCE LEVELS

Flight	Pass	Δg[1]	Turbulence Level
2	1	0.04	CALM
2	2	0.02	CALM
2	3	0.02	CALM
2	4	0.01	CALM
2	5	0.03	CALM
2	6	0.03	CALM
2	7	0.06	CALM
2	8	0.05	CALM
2	9	0.02	CALM
2	10	0.03	CALM
2	11	0.04	CALM
2	12	0.03	CALM
2	13	0.01	CALM
2	14	0.04	CALM
2	15	0.05	CALM
2	16	Erroneous Data	

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C4
FLIGHT 3 TURBULENCE LEVELS

Flight	Pass	Δg[1]	Turbulence Level
3	1	0.02	CALM
3	2	0.07	CALM
3	3	No Data Available	
3	4	0.04	CALM
3	5	0.04	CALM
3	6	0.03	CALM
3	7	0.04	CALM
3	8	0.06	CALM
3	9	0.02	CALM
3	10	Erroneous Data	
3	11	0.08	CALM
3	12	0.02	CALM
3	13	0.04	CALM
3	14	0.05	CALM
3	15	0.07	CALM

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C5
FLIGHT 4 TURBULENCE LEVELS

Flight	Pass	Δg^1	Turbulence Level
4	1	0.17	MEDIUM
4	2	0.16	MEDIUM
4	3	0.24	MEDIUM
4	4	0.36	TURBULENT
4	5	0.25	MEDIUM
4	6	0.37	TURBULENT
4	7	0.35	TURBULENT
4	8	0.79	TURBULENT
4	9	0.18	MEDIUM
4	10	0.56	TURBULENT
4	11	0.19	MEDIUM
4	12	0.14	MEDIUM
4	13	0.29	MEDIUM
4	14	Erroneous Data	
4	15	0.23	MEDIUM
4	16	0.38	TURBULENT
4	17	0.34	TURBULENT
4	18	0.33	TURBULENT

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C6
FLIGHT 5 TURBULENCE LEVELS

Flight	Pass	Δg^1	Turbulence Level
5	1	0.65	TURBULENT
5	2	0.34	TURBULENT
5	3	0.33	TURBULENT
5	4	0.45	TURBULENT
5	5	0.37	TURBULENT
5	6	0.54	TURBULENT
5	7	0.36	TURBULENT
5	8	No Data Available	
5	9	0.35	TURBULENT
5	10	0.24	MEDIUM
5	11	0.50	TURBULENT
5	12	0.62	TURBULENT
5	13	0.52	TURBULENT
5	14	0.20	MEDIUM
5	15	0.18	MEDIUM
5	16	0.18	MEDIUM

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C7
FLIGHT 6 TURBULENCE LEVELS

Flight	Pass	Δg[1]	Turbulence Level
6	1	0.21	MEDIUM
6	2	0.13	MEDIUM
6	3	0.23	MEDIUM
6	4	0.11	MEDIUM
6	5	0.25	MEDIUM
6	6	0.38	TURBULENT
6	7	0.31	TURBULENT
6	8	0.30	TURBULENT
6	9	0.23	MEDIUM
6	10	0.32	TURBULENT
6	11	0.29	MEDIUM
6	12	0.42	TURBULENT
6	13	0.24	MEDIUM
6	14	0.64	TURBULENT
6	15	0.13	MEDIUM
6	16	0.25	MEDIUM

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C8
FLIGHT 7 TURBULENCE LEVELS

Flight	Pass	Δg	Turbulence Level
7	1	No Data, Bird Strike	

Note: Δg – delta force

Table C9
FLIGHT 8 TURBULENCE LEVELS

Flight	Pass	Δg[1]	Turbulence Level
8	1	0.20	MEDIUM
8	2	0.29	MEDIUM
8	3	0.22	MEDIUM
8	4	0.14	MEDIUM
8	5	0.16	MEDIUM
8	6	0.37	TURBULENT
8	7	0.13	MEDIUM
8	8	0.28	MEDIUM
8	9	0.12	MEDIUM
8	10	0.35	TURBULENT
8	11	0.57	TURBULENT
8	12	0.25	MEDIUM
8	13	0.28	MEDIUM
8	14	0.37	TURBULENT
8	15	Erroneous Data	
8	16	Erroneous Data	
8	17	0.60	TURBULENT
8	18	0.11	MEDIUM
8	19	0.45	TURBULENT
8	20	0.36	TURBULENT
8	21	0.53	TURBULENT
8	22	0.13	MEDIUM
8	23	0.59	TURBULENT
8	24	0.11	MEDIUM

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C10
FLIGHT 9 TURBULENCE LEVELS

Flight	Pass	Δg[1]	Turbulence Level
9	1	0.49	TURBULENT
9	2	0.29	MEDIUM
9	3	0.33	TURBULENT
9	4	0.82	TURBULENT
9	5	0.36	TURBULENT
9	6	0.25	MEDIUM
9	7	0.50	TURBULENT
9	8	0.34	TURBULENT
9	9	0.79	TURBULENT
9	10	0.70	TURBULENT
9	11	0.40	TURBULENT
9	12	0.44	TURBULENT
9	13	0.30	TURBULENT
9	14	0.15	MEDIUM
9	15	0.33	TURBULENT
9	16	0.68	TURBULENT

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C11
FLIGHT 10 TURBULENCE LEVELS

Flight	Pass	Δg[1]	Turbulence Level
10	1	0.26	MEDIUM
10	2	0.27	MEDIUM
10	3	0.53	TURBULENT
10	4	0.29	MEDIUM
10	5	0.34	TURBULENT
10	6	Erroneous Data	
10	7	0.35	TURBULENT
10	8	0.22	MEDIUM
10	9	0.20	MEDIUM
10	10	0.13	MEDIUM
10	11	Erroneous Data	
10	12	0.40	TURBULENT
10	13	0.42	TURBULENT

Note: Δg – delta force

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

Table C12
FLIGHT 11 TURBULENCE LEVELS

Flight	Pass	Δg	Turbulence Level
11	1	DAS Tape Corrupted	

Note: Δg – delta force

APPENDIX D

FLIGHT TEST PROCEDURE

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FLIGHT TEST PROCEDURE

Each test flight consisted of approximately 15 passes. A pass was defined as a 10-second trim shot, followed by a series of three pitch doublets, followed by another 10-second trim shot, and finishing with sinusoidal pitch inputs of typically 60 seconds in duration.

TRIM SHOT NO. 1

Each pass started with a 10-second trim shot to determine the level of turbulence in the local area. The trim shot was accomplished with the aircraft straight, level, and unaccelerated with the pilot aiming for the target flight condition of 4,000 feet PA and 0.65 Mach number. Data bands and tolerances for the trim shot are given in Table D1. Turbulence levels are defined in Table D2.

These values were chosen based on simulation and previous flight data. Normal acceleration typically varied only 0.05 g from 1-g trim flight in previous F-16B calm air data collected during early morning flights at low altitude. The calm air value was chosen to allow for slight differences that might have been observed during HAVE DERIVATIVES testing but that would not have had an appreciable effect on the accuracy of stability derivative estimate results. The turbulent air value was chosen to ensure that there would be enough turbulence to see an effect on the aircraft responses, and consequently greater errors in the derivative estimates, while not being so large that the turbulence level might not have been encountered during the test program.

PITCH DOUBLET

Following the trim shot, the pilot accomplished three successive pitch doublets. The pilot performed a pitch doublet, waited for the aircraft response to subside, and then repeated a second and then a third pitch doublet. The control room, if available, monitored angle of attack (AOA) and pitch rate to ensure they stayed within ±5 degrees of trim AOA and within ±20 degrees per second pitch rate, respectively. These limits were set to ensure that the responses did not violate linearity assumptions used in the analysis. The control room, if available, advised the pilot of maneuver quality following each set of three pitch doublets.

Table D1
TRIM SHOT DATA BANDS AND TOLERANCES

Parameter	Data Band	Tolerance
Altitude (ft)	±1000	±100
Mach Number	±0.02	±0.01

Table D2
TURBULENCE LEVEL DEFINITIONS

Turbulence Level	ΔNormal Acceleration (Δg)[1]
Calm Air	$\lvert \Delta n_z \rvert \leq 0.1$
Turbulent Air	$0.3 \leq \lvert \Delta n_z \rvert$

Notes: 1. Δ - increment of change
2. g - acceleration due to gravity
3. n_z - normal acceleration

[1]Change in normal acceleration from 1 g at a frequency of 1 radian per second

TRIM SHOT NO. 2

After the pitch doublets, the pilot accomplished a second straight, level, and unaccelerated trim shot aiming for the same target flight condition for the same reasons as the first trim shot. The data bands and tolerances in Table D1 applied for the second trim shot as well.

PITCH INPUT

Following the second trim shot, the pilot performed a series of sinusoidal pitch inputs. Two different types of inputs were used during the HAVE DERIVATIVES project. The first was a pitch frequency sweep beginning at a frequency well below the test aircraft short period undamped natural frequency of approximately 1 radian per second, and progressing slowly to a frequency well above 1 radian per second. To ensure consistency between passes, and between pilots, a system of counting during the inputs was devised. The first input was stick aft for 3 seconds followed by stick forward for 6 seconds followed by stick aft for 6 seconds. Because the first input was equal to one-quarter of the first cycle period, the rest of the cycles were symmetric about the trim flight condition. This technique aided the pilot in keeping the aircraft about the trim flight condition while making the inputs, thereby minimizing chances that linearity assumptions would be violated. The subsequent cycles were decreased by one count each period. The input was terminated when approximately 60 seconds of data were collected. Using this technique, responses were gathered from approximately 0.5 to 10 radians per second. The pitch frequency sweep technique was used for flights 1 through 8. In an effort to determine if an alternate technique might have given better results, a different sinusoidal pitch input described in the following paragraph was used during flights 9 and 10.

Because the optimal parameter estimation of the longitudinal derivatives associated with the short-period mode of motion resulted from exciting that mode sufficiently, a pitch frequency dwell, which concentrated the inputs around the test aircraft short-period undamped natural frequency of approximately 1 radian per second, was devised. To accomplish the input consistently, the pilots made sinusoidal pitch inputs lasting approximately 6 seconds per cycle for the 60-second duration of the total sweep. The cycles were centered about the trim flight condition, as before, to preserve linearity of the aircraft responses.

For both types of pitch inputs, the control room, if available, monitored AOA and pitch rate and informed the pilot if the limits of a ±5-degree AOA or ±20-degree per second pitch rate were exceeded.

If a particular type of turbulence level, turbulent air or calm air, was initially encountered in a particular area, but part way through the test flight, that turbulence level no longer existed, the location of the test was moved to find the desired turbulence level. Testing was terminated when the test aircraft had the minimum amount of fuel necessary to return to base with required normal reserves.

APPENDIX E

PARAMETER LISTS

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PARAMETER LISTS

The following parameters were recorded in flight using the F-16B airborne test instrumentation system (ATIS) data acquisition system (DAS) (Table E1). The same parameters were also recorded real-time to a computer file using the ATIS telemetry system installed aboard the F-16 aircraft, if available, to provide a backup to the DAS. In addition, the flight test engineer in the test aircraft recorded from rear cockpit gages, true airspeed, Mach number, pressure altitude, and total fuel quantity during each trim shot.

Incompressible dynamic pressure (qbar) was computed by the Aydin processor using the following equation:

$$\text{qbar} = 0.7\left[2116.22\left(1 - 6.87558\text{x}10^{-6}\text{H}_c\right)^{5.2559}\right]\text{M}^2$$

where H_c and M were measured in flight.

The parameters listed in Tables E2 through E11 were used by PCPID to accomplish stability derivative estimation.

Table E1
PARAMETERS RECORDED DURING FLIGHT

Parameter Name	Type	Source	Range	Resolution	Samples/ Second
Time	Digital	Data Bus	0 to 99:59:59.99 (hr:min:sec.milsec)	1 milsec	66.67
Right Horizontal Stabilator Position	Analog	LVDT[1,2]	$\pm$23.15 deg	0.2000 deg	66.67
Angle of Attack (AOA)	Analog	Nose Boom AOA Vane[3,4,5]	$\pm$60 deg	0.0400 deg	66.67
Pitch Angle	16 Bit Digital	INS	$\pm$110 deg	0.0050 deg	66.67
Pitch Rate	14 Bit Digital	HUD	$\pm$45 deg/sec	0.0220 deg/sec	66.67
Normal Acceleration	12 Bit Digital	HUD[6,7]	$\pm$10 g	0.0080 g	66.67
True Airspeed	15 Bit Digital	CADC	70 to 1,700 KTAS (118.3 to 2,873 fps)	0.125 KTAS (0.211 fps)	8.33
Mach Number	15 Bit Digital	CADC	0.1 to 3.0	0.0002	8.33
Pressure Altitude	16 Bit Digital	CADC	-1,500 to 80,000 ft	2.5 ft	8.33
Total Fuel Quantity	Analog	Transducer	0 to 5,100 lb	11 lb	8.33

Notes:
1. hr:min:sec.milsec - hour(s):minute(s):second(s).millisecond(s)
2. LVDT - linear variable displacement transducer
3. HUD - head-up display
4. CADC - central air data computer

[1]Transducer was calibrated once before first test flight
[2]Five pole low-pass Butterworth filter with 9.5-hertz cutoff frequency applied to signal
[3]No corrections were made for upwash, boom bending or location from reference cg
[4]Angle-of-attack vane was calibrated once before first test flight
[5]Five pole low-pass Butterworth filter with 9.5-hertz cutoff frequency applied to signal
[6]Normal accelerometer was located at 6.87 feet aft of flight station 0.0, 0.64 feet left of centerline and 8.13 feet above ground
[7]No corrections were made for location from reference cg

Table E2
CONSTANTS USED BY PCPID

Constants	Description	Units
area	Aircraft reference area	ft^2
chord	Aircraft reference chord	ft
span	Aircraft reference span	ft
mass	Aircraft mass	slugs
xcg	Distance from reference cg X-coordinate	ft
ycg	Distance from reference cg Y-coordinate	ft
zcg	Distance from reference cg Z-coordinate	ft
ix	Aircraft roll moment of inertia	slug ft^2
iy	Aircraft pitch moment of inertia	slug ft^2
iz	Aircraft yaw moment of inertia	slug ft^2
ixy	Aircraft X-Y product of inertia	slug ft^2
ixz	Aircraft X-Z product of inertia	slug ft^2
iyz	Aircraft Y-Z product of inertia	slug ft^2

Note: PCPID - Personal Computer Parameter Identification

Table E3
INSTRUMENT CORRECTIONS USED BY PCPID

Parameter[1]	Description	Units
ka	Upwash factor for angle-of-attack sensor	N/D
xa	X-coordinate of angle-of-attack sensor	ft
ya	Y-coordinate of angle-of-attack sensor	ft
za	Z-coordinate of angle-of-attack sensor	ft
xan	X-coordinate of normal accelerometer	ft
yan	Y-coordinate of normal accelerometer	ft
zan	Z-coordinate of normal accelerometer	ft

Notes: 1. N/D - nondimensional
2. PCPID - Personal Computer Parameter Identification

[1]All sensor coordinates measured from reference cg location of 26.72 feet aft of flight station 0.0, on centerline and 7.58 feet above ground

Table E4
PARAMETERS COMPUTED BY PCPID FROM FLIGHT DATA

Extra	Description	Units
avg_v	Average velocity	ft/s
avg_mach	Average Mach number	N/D
avg_qbar	Average dynamic pressure	psf
alt	Average Altitude	ft
avg_alpha	Average angle of attack	deg
avg_theta	Average pitch angle	deg

Notes: 1. N/D - nondimensional
2. PCPID - Personal Computer Parameter Identification

Table E5
FLIGHT DATA CONTROL INPUT PARAMETER USED BY PCPID

Control	Description	Units
de	Right horizontal stabilator deflection	deg

Note: PCPID – Personal Computer Parameter Identification

Table E6
FLAG STATEMENTS USED WITHIN PCPID

Flag	Description
use_avg_alpha	Use average angle of attack
use_avg_mach	Use average mach number
use_avg_qbar	Use average dynamic pressure
use_avg_theta	Use average pitch angle
use_avg_v	Use average velocity

Note: PCPID – Personal Computer Parameter Identification

Table E7
OPTION PARAMETERS USED BY PCPID

Option	Description
apfact	A priori overall weighting factor
bound	Iteration Convergence bound
graddelt	Gradient delta (step size)
gradmeth	Gradient computation method
integ	Integration method (equations of motion)
line	Linesearch parameters
min	Cost function minimization method
msglevel	Screen output message level

Note: PCPID – Personal Computer Parameter Identification

Table E8
AIRCRAFT STATES CALCULATED BY PCPID

State	Description
alpha	Angle of attack equation
theta	Pitch angle equation
q	Pitch rate equation

Note: PCPID – Personal Computer Parameter Identification

Table E9
RESPONSE BIASES COMPUTED BY PCPID

Parameters	Description	Units
qbias	Measurement bias to pitch rate	deg/s
anbias	Measurement bias to normal acceleration	g

Note: PCPID – Personal Computer Parameter Identification

Table E10
AIRCRAFT RESPONSES COMPUTED BY PCPID

Output	Description
alpha	Angle of attack
theta	pitch angle
q	pitch rate
an	Normal acceleration

Note: PCPID - Personal Computer Parameter Identification

Table E11
LONGITUDINAL DERIVATIVES ESTIMATED BY PCPID

Parameter	Description	Units
cnorm0	Normal force coefficient bias	N/D
cnorma	Normal force coefficient due to angle of attack	per deg
cnormde	Normal force coefficient due to elevator control	per deg
cm0	Pitching moment coefficient due to aerodynamic bias	N/D
cma	Pitching moment coefficient due to angle of attack	per deg
cmq	Pitching moment coefficient due to pitch rate	per rad
cmde	Pitching moment coefficient due to elevator control	per deg

Notes: 1. N/D - nondimensional
2. PCPID - Personal Computer Parameter Identification
3. rad - radian

APPENDIX F

DATA PROCESSING

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DATA PROCESSING

This appendix describes the steps used by the HAVE DERIVATIVES team to accomplish postflight data processing. The first step in the data reduction process was to transfer flight data from the airborne test instrumentation system (ATIS) data acquisition system (DAS) tape to computer files using the USAF Test Pilot School (TPS) Aydin processor. Next, the USAF TPS flight test analysis software (FTAS) was used to convert the files from *.ayd format to tab delimited flat ASCII format (Reference 11). The files could then be opened in MATLAB® by HDPROCES.M, a postflight data processing routine written by the HAVE DERIVATIVES team to automate the data reduction process.

This appendix also describes, in detail, the processes used to calculate stability derivative estimates and associated results using Personal Computer Parameter Identification (PCPID) alone and in conjunction with the HAVE DERIVATIVES process.

HDPROCESS

The following MATLAB® script file, HDPROCES.M, was used to process data prior to entry into PCPID.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%       HAVE DERIVATIVES PROCESS (hdproces.m)              15 Sept 97
%
%       This MATLAB® script file was written by the HAVE DERIVATIVES Test Management Project Team
to
%       automate the data reduction process from the point of having flight data files in tab delimited flat
%       ASCII format to the GetData format that could be input into PCPID.
%
%       HDPROCES is interactive. First the user is asked to select the desired flight data file and ensure that
%       its columns are correctly defined. The user is then prompted to define the bands to be used to filter
%       wild points from the files. Next the user interactively divides the files into the set of three doublets
%       and the pitch sweep. The doublets portion of the file is saved in the GetData format and is available
%       for PCPID input. The sweep portion is further processed by transforming the input and response
%       signals into the frequency domain with MATLAB's® fast Fourier transform routine. In the frequency
%       domain, the signals are ensemble averaged to minimize randomness introduced by noise such as
%       turbulence. The ensemble averaged input and response signals are used to estimate transfer functions
%       using the transfer function estimate (tfe.m) routine in MATLAB's® Signal Processing Toolbox®. The
%       average frequency responses are then transformed back into the time domain with MATLAB's®
%       inverse fast Fourier transform where they become the system's discrete pulse responses. These
%       discrete pulse responses and a simulated unit pulse input are saved in the GetData format, as before,
%       for PCPID processing.
%
%       HDPROCES also prompts the user to define the trim shot period on a plot of normal acceleration
%       versus time. HDPROCES uses that time slice to calculate the average normal acceleration variation at
%       1 radian per second, approximately the test aircraft short period undamped natural frequency. This
%       value is hand recorded and used to quantify the turbulence level for that simulation based on HAVE
%       DERIVATIVES defined turbulence level categories.
%
%       Finally, HDPROCES calls MASSCALC, a FORTRAN program written by Chris Nagy of Quartic
%       Engineering Inc. (Reference 7). MASSCALC computes the mass and inertia properties of a
%       Block 15 F-16B given the total fuel weight. The output, including mass, cg location and moments and
%       products of inertia, are hand recorded and used as input to PCPID.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
close all          % Closes all figure windows
clear all          % Clears MATLAB® memory
clc                % Clears command window

%%%%% Load input file

[datfile,path]=uigetfile('*.*','Choose input file.');
nletters=max(size(datfile));
varname=datfile(1,1:nletters-4);
eval(['load ',path,datfile,'-ascii']);
input_file=eval([varname '(:,:)']);

%%%%% Find out if operator wishes to use default columns or redefine their own

disp('')
disp('Default Column Order is:        ')
disp('')
disp('Line                                          1')
disp('Time (s)                                      2')
disp('M_IC                                          3')
disp('QBAR                                          4')
disp('V_T                                           5')
disp('ALPHA                                         6')
disp('HORIZONTAL_TAIL_POSITION_RIGHT                7')
disp('N_Z                                           8')
disp('Q                                             9')
disp('H_IC                                          10')
disp('W_F                                           11')
disp('THETA                                         12')
disp('')
disp('Enter 1 if you wish to re-define the column order.')
column_order_answer=input('Enter 2 if you wish to go with the default values: ');
disp('')

if column_order_answer~=2
        input_file(1:5,:)

        disp('')
        actual_line = input('Type Line Number column # and press ENTER: ');
        actual_time = input('Type Time column # and press ENTER: ');
        actual_Mic  = input('Type Mach column # and press ENTER: ');
        actual_Qbar = input('Type Qbar column # and press ENTER: ');
        actual_Vt   = input('Type Vt column # and press ENTER: ');
        actual_alpha = input('Type Alpha column # and press ENTER: ');
        actual_Hstab = input('Type Horizontal Stab column # and press ENTER: ');
        actual_Nz   = input('Type Nz column # and press ENTER: ');
        actual_Q    = input('Type Q column # and press ENTER: ');
        actual_Hic  = input('Type Alt column # and press ENTER: ');
        actual_Wf   = input('Type Wf column # and press ENTER: ');
        actual_theta = input('Type Theta column # and press ENTER: ');
        disp('')
else
        actual_line = 1;
        actual_time = 2;
        actual_Mic  = 3;
```

```
        actual_Qbar = 4;
        actual_Vt  = 5;
        actual_alpha = 6;
        actual_Hstab = 7;
        actual_Nz  = 8;
        actual_Q   = 9;
        actual_Hic  = 10;
        actual_Wf  = 11;
        actual_theta = 12;
end

clc     % Clears command window

%%%%% Determine if operator wishes to use the default band pass filter ranges or if they wish to
%%%%% define their own

disp('')
disp('Default band pass filter ranges are:      ')
disp('')
disp('Line                                        [0, 1000000]')
disp('Time                                        [time (s) in first line, time (s) in last line]')
disp('M_IC                                        [0.6, 0.7]')
disp('QBAR                                        [450, 650]')
disp('V_T                                         [600, 800]')
disp('ALPHA                                       [-2, 8]')
disp('HORIZONTAL_TAIL_POSITION_RIGHT              [-10, 10]')
disp('N_Z                                         [-3, 4]')
disp('Q                                           [-20, 20]')
disp('H_IC                                        [3000, 5000]')
disp('W_F                                         [1000, 8000]')
disp('THETA                                       [-10, 10]')
disp('')
disp('Enter 1 if you wish to define your own band pass filter ranges.')
band_pass_range_answer=input('Enter 2 if you wish to use the default values: ');
disp('')

if band_pass_range_answer~=2

        disp('')
        Line=input('Enter Min an Max value for Line Numbers: [min, max] ');
        Time=input('Enter Min an Max value for Time: [min, max] ');
        M_IC=input('Enter Min an Max value for M_ic: [min, max] ');
        QBAR=input('Enter Min an Max value for Qbar: [min, max] ');
        V_T=input('Enter Min an Max value for V_T: [min, max] ');
        ALPHA=input('Enter Min an Max value for Alpha: [min, max] ');
        HORIZONTAL_TAIL_POSITION_RIGHT=input('Enter Min an Max value for Right Horizontal

                Tail Position: [min, max] ');
        N_Z=input('Enter Min an Max value for N_Z: [min, max] ');
        Q=input('Enter Min an Max value for Q (Pitch Rate): [min, max] ');
        H_IC=input('Enter Min an Max value for H_ic: [min, max] ');
        W_F=input('Enter Min an Max value for W_F (Fuel): [min, max] ');
        THETA=input('Enter Min an Max value for Theta (Pitch angle): [min, max] ');
        disp('')

else
```

```
        Line=[0, 1000000];
        Time=[input_file(1,actual_time), input_file(length(input_file),actual_time)];
        M_IC=[0.6, 0.7];
        QBAR=[450, 650];
        V_T=[600, 800];
        ALPHA=[-2, 8];
        HORIZONTAL_TAIL_POSITION_RIGHT=[-10, 10];
        N_Z=[-3, 4];
        Q=[-20, 20];
        H_IC=[3000, 5000];
        W_F=[1000, 8000];
        THETA=[-10, 10];
end

clc     % Clears command window

%%%%% Determine size of input file

[rows_input_file,columns_input_file] = size(input_file);

%%%%% Employ bandpass filters defined above

%%%%%%%%% Filters Line column

Good_Line_rows=find(input_file(:,actual_line)>=Line(1) & input_file(:,actual_line)<=Line(2));
input_file=input_file(Good_Line_rows,:);

%%%%%%%%% Filters Time column

Good_Time_rows=find(input_file(:,actual_time)>=Time(1) & input_file(:,actual_time)<=Time(2));
input_file=input_file(Good_Time_rows,:);

%%%%%%%%% Filters M_IC column

Good_M_IC_rows=find(input_file(:,actual_Mic)>=M_IC(1) & input_file(:,actual_Mic)<=M_IC(2));
input_file=input_file(Good_M_IC_rows,:);

%%%%%%%%% Filters QBAR column

Good_QBAR_rows=find(input_file(:,actual_Qbar)>=QBAR(1) & input_file(:,actual_Qbar)<=QBAR(2));
input_file=input_file(Good_QBAR_rows,:);

%%%%%%%%% Filters ALPHA column

Good_ALPHA_rows=find(input_file(:,actual_alpha)>=ALPHA(1) &
                        input_file(:,actual_alpha)<=ALPHA(2));
input_file=input_file(Good_ALPHA_rows,:);

%%%%%%%%% Filters HORIZONTAL_TAIL_POSITION_RIGHT column

Good_HORIZONTAL_TAIL_POSITION_RIGHT_rows=find(input_file(:,actual_Hstab)>=
                        HORIZONTAL_TAIL_POSITION_RIGHT(1) &
                        input_file(:,actual_Hstab)<=HORIZONTAL_TAIL_POSITION_RIGHT(2));
input_file=input_file(Good_HORIZONTAL_TAIL_POSITION_RIGHT_rows,:);
%%%%%%%%% Filters N_Z column
```

```
Good_N_Z_rows=find(input_file(:,actual_Nz)>=N_Z(1) & input_file(:,actual_Nz)<=N_Z(2));
input_file=input_file(Good_N_Z_rows,:);

%%%%%%%% Filters Q column

Good_Q_rows=find(input_file(:,actual_Q)>=Q(1) & input_file(:,actual_Q)<=Q(2));
input_file=input_file(Good_Q_rows,:);

%%%%%%%% Filters H_IC column

Good_H_IC_rows=find(input_file(:,actual_Hic)>=H_IC(1) & input_file(:,actual_Hic)<=H_IC(2));
input_file=input_file(Good_H_IC_rows,:);

%%%%%%%% Filters V_T column

Good_V_T_rows=find(input_file(:,actual_Vt)>=V_T(1) & input_file(:,actual_Vt)<=V_T(2));
input_file=input_file(Good_V_T_rows,:);

%%%%%%%% Filters W_F column

Good_W_F_rows=find(input_file(:,actual_Wf)>=W_F(1) & input_file(:,actual_Wf)<=W_F(2));
input_file=input_file(Good_W_F_rows,:);

%%%%%%%% Filters THETA column

Good_THETA_rows=find(input_file(:,actual_theta)>=THETA(1) &
                        input_file(:,actual_theta)<=THETA(2));
input_file=input_file(Good_THETA_rows,:);

%%%%% Plot Variables vs Time

figure
Subplot(2,1,1);
plot(input_file(:,actual_line),input_file(:,actual_time)),title(['PRESS ENTER TO CONTINUE']);
xlabel('Line_number'),ylabel('Time (s)')

Subplot(2,1,2);
plot(input_file(:,actual_time),input_file(:,actual_Mic));
xlabel('Time (s)'),ylabel('Mic')
input('');

figure
Subplot(2,1,1);
plot(input_file(:,actual_time),input_file(:,actual_Qbar)),title(['PRESS ENTER TO CONTINUE']);
xlabel('Time (s)'),ylabel('Qbar')

Subplot(2,1,2);
plot(input_file(:,actual_time),input_file(:,actual_alpha));
xlabel('Time (s)'),ylabel('Alpha')
input('');


figure
Subplot(2,1,1);
plot(input_file(:,actual_time),input_file(:,actual_Hstab)),title(['PRESS ENTER TO CONTINUE']);
xlabel('Time (s)'),ylabel('Hstab')
```

```
Subplot(2,1,2);
plot(input_file(:,actual_time),input_file(:,actual_Nz));
xlabel('Time (s)'),ylabel('Nz')
input('');

figure
Subplot(2,1,1);
plot(input_file(:,actual_time),input_file(:,actual_Q)),title(['PRESS ENTER TO CONTINUE']);
xlabel('Time (s)'),ylabel('Q (pitch rate)')

Subplot(2,1,2);
plot(input_file(:,actual_time),input_file(:,actual_Hic));
xlabel('Time (s)'),ylabel('Hic')
input('');

figure
Subplot(2,1,1);
plot(input_file(:,actual_time),input_file(:,actual_Vt)),title(['PRESS ENTER TO CONTINUE']);
xlabel('Time (s)'),ylabel('Vt')

Subplot(2,1,2);
plot(input_file(:,actual_time),input_file(:,actual_Wf));
xlabel('Time (s)'),ylabel('Wf')
input('');

figure
Subplot(2,1,1);
plot(input_file(:,actual_time),input_file(:,actual_theta)),title(['PRESS ENTER TO CONTINUE']);
xlabel('Time (s)'),ylabel('Theta')
input('');

%%%%% Subdivide the combined doublet/frequency sweep file to two separate files,
%%%%% one a doublet file and one a frequency sweep file

[rows_new_input_file, columns_new_input_file]=size(input_file);

figure
plot(input_file(:,actual_time), input_file(:,actual_alpha))
title(['Put crosshairs at end of third doublet response and click left mouse button'])
xlabel(['Time (sec)']),ylabel(['Alpha (deg)']);

split_time=ginput(1);
split_line=find(input_file(:,actual_time)>=split_time(1,1)-.01 &
input_file(:,actual_time)<=split_time(1,1)+.01);

doublet_input_file=input_file(1:split_line(1),:);
sweep_input_file=input_file(split_line(1):rows_new_input_file,:);


figure
subplot(2,1,1)
plot(doublet_input_file(:,actual_time), doublet_input_file(:,actual_alpha))
title(['PRESS ENTER TO CONTINUE']);
subplot(2,1,2)
plot(sweep_input_file(:,actual_time), sweep_input_file(:,actual_alpha));
```

```
input('');

%%%%% Determine level of turbulence

%%%%% Plot Nz and have operator define start and end of either trim shot

figure
plot(input_file(:,actual_time), input_file(:,actual_Nz))
title(['Click crosshairs first at start and then end of either trim shot.'])
xlabel(['Time (sec)']),ylabel(['Nz (g)']);

[turbulence_X_time, turbulence_Y_time]=ginput(2);

turbulence_start_line=find(input_file(:,actual_time)>=turbulence_X_time(1)-.01 &
input_file(:,actual_time)<=turbulence_X_time(1)+.01);
turbulence_end_line=find(input_file(:,actual_time)>=turbulence_X_time(2)-.01 &
input_file(:,actual_time)<=turbulence_X_time(2)+.01);

%%%%% Calculate and plot PSD of Nz

[Pxx,Freq]=psd(input_file(turbulence_start_line:turbulence_end_line,actual_Nz),[],66.6667,[],[],'mean');

figure
plot(Freq,10*log10(Pxx))
grid
ylabel('Power Spectrum Magnitude (dB)');
xlabel('Frequency (Hz)');
title('Nz PSD (PRESS ENTER TO CONTINUE)');
input('');

%%%%% Interpolate to find what PSD value corresponds to 1 Hz

Pxx_at_1Hz=interp1(Freq,Pxx,1);          % 1 Here refers to 1 Hz

g_at_1Hz=sqrt(Pxx_at_1Hz*1);             % 1 Here refers to 1 Hz

Turbulence=g_at_1Hz

%%%%% Define doublet signals to be saved in GetData (*.gtd) format

Time=doublet_input_file(:,actual_time);

Mach=doublet_input_file(:,actual_Mic);

Qbar=doublet_input_file(:,actual_Qbar);

Alpha=doublet_input_file(:,actual_alpha);

RStab=doublet_input_file(:,actual_Hstab);

Nz=doublet_input_file(:,actual_Nz);

Q=doublet_input_file(:,actual_Q);

Alt=doublet_input_file(:,actual_Hic);
```

```
Vt=doublet_input_file(:,actual_Vt);

Theta=doublet_input_file(:,actual_theta);

%%%%% Save doublet signals in *.gtd format

gdsave('G:\projects\Turb_D\f10d16.gtd', Time, Mach, Qbar, Alpha, RStab, Nz, Q, Alt, Vt, Theta)

%%%%% Define sinusoidal sweep signals for processing

Time=sweep_input_file(:,actual_time);

Mach=sweep_input_file(:,actual_Mic);

Qbar=sweep_input_file(:,actual_Qbar);

Alpha=sweep_input_file(:,actual_alpha);

RStab=sweep_input_file(:,actual_Hstab);

Nz=sweep_input_file(:,actual_Nz);

Q=sweep_input_file(:,actual_Q);

Alt=sweep_input_file(:,actual_Hic);

Vt=sweep_input_file(:,actual_Vt);

Theta=sweep_input_file(:,actual_theta);

%%%%% Define Transfer Function Estimate parameters

fftl = 2048;                                              % FFT Length
po = 50;                                                  % Percent Overlap
ovlp = round(po*.01*fftl);                                % Number of Points Overlapped
t = (0:1/67:(1/67)*fftl-(1/67))';                         % Time Vector [sec]
frs = ((2*pi*67)/fftl: (2*pi*67)/fftl: (2*pi*67)/2)';     % Frequency Vector [rad/sec]

%%%%% Using the Transfer Function Estimate (tfe) MATLAB® command from the Signal Processing
%%%%% Toolbox® transform input and responses into frequency domain, ensemble average signals
%%%%% and estimate transfer functions.

H_Alpha_RStab = tfe(RStab,Alpha,fftl,67,[],ovlp);
H_Q_RStab = tfe(RStab,Q,fftl,67,[],ovlp);
H_Nz_RStab = tfe(RStab,Nz,fftl,67,[],ovlp);
H_Theta_RStab = tfe(RStab,Theta,fftl,67,[],ovlp);

%%%%% Plot magnitude (dB) of the average frequency responses and prompt user to define a cutoff
%%%%% frequency above which the magnitude and phase values in the matrix will be set to 0.

figure

subplot(4,1,1),semilogx(frs,20*log10(abs(H_Alpha_RStab(1:length(frs),1))))
title(['Alpha / Right Horizontal Stab Frequency Magnitude Response (SELECT CUTOFF FREQUENCY)'])
ylabel(['Magnitude (dB)'])
```

```
subplot(4,1,2),semilogx(frs,20*log10(abs(H_Q_RStab(1:length(frs),1))))
title(['Q / Right Horizontal Stab Frequency Magnitude Response']),ylabel(['Magnitude (dB)'])

subplot(4,1,3),semilogx(frs,20*log10(abs(H_Nz_RStab(1:length(frs),1))))
title(['Nz / Right Horizontal Stab Frequency Magnitude Response']),ylabel(['Magnitude (dB)'])

subplot(4,1,4),semilogx(frs,20*log10(abs(H_Theta_RStab(1:length(frs),1))))
title(['Theta / Right Horizontal Stab Frequency Magnitude Response'])
xlabel(['Frequency (Hz)']),ylabel(['Magnitude (dB)'])

cutoff_freq = ginput(1);
cutoff_line = find(frs(:,1)<=cutoff_freq(1,1));

%%%%% Define clipped average frequency responses

H_Alpha_RStab_Clipped = H_Alpha_RStab(1:length(cutoff_line),:);
H_Q_RStab_Clipped = H_Q_RStab(1:length(cutoff_line),:);
H_Nz_RStab_Clipped = H_Nz_RStab(1:length(cutoff_line),:);
H_Theta_RStab_Clipped = H_Theta_RStab(1:length(cutoff_line),:);

%%%%% Transform average frequency responses back into time domain as discrete pulse responses
%%%%% using IFFT.

h_Alpha_RStab_impulse = real(ifft(H_Alpha_RStab_Clipped,fftl));
h_Q_RStab_impulse = real(ifft(H_Q_RStab_Clipped,fftl));
h_Nz_RStab_impulse = real(ifft(H_Nz_RStab_Clipped,fftl));
h_Theta_RStab_impulse = real(ifft(H_Theta_RStab_Clipped,fftl));

%%%%% Plot complete discrete pulse responses and prompt user to define cutoff time to remove
%%%%% extraneous response.

figure

subplot(4,1,1),plot(t(1:length(h_Alpha_RStab_impulse),1),h_Alpha_RStab_impulse)
title(['Alpha Discrete Pulse Response (SELECT CUTOFF TIME)']),ylabel(['Alpha (deg)'])

subplot(4,1,2),plot(t(1:length(h_Q_RStab_impulse),1),h_Q_RStab_impulse)
title(['Q Discrete Pulse Response']),ylabel(['Q (deg/sec)'])

subplot(4,1,3),plot(t(1:length(h_Nz_RStab_impulse),1),h_Nz_RStab_impulse)
title(['Nz Discrete Pulse Response']),ylabel(['Nz (g)'])


subplot(4,1,4),plot(t(1:length(h_Theta_RStab_impulse),1),h_Theta_RStab_impulse)
title(['Theta Discrete Pulse Response']),ylabel(['Theta (deg)']),xlabel(['Time (sec)'])

cutoff_time = ginput(1);
cutoff_line = find(t(:,1)<=cutoff_time(1,1));

%%%%% Define and plot clipped discrete pulse responses based on user defined cutoff time.

h_Alpha_RStab_impulse_Clipped = h_Alpha_RStab_impulse(1:length(cutoff_line),:);
h_Q_RStab_impulse_Clipped = h_Q_RStab_impulse(1:length(cutoff_line),:);
h_Nz_RStab_impulse_Clipped = h_Nz_RStab_impulse(1:length(cutoff_line),:);
h_Theta_RStab_impulse_Clipped = h_Theta_RStab_impulse(1:length(cutoff_line),:);
```

```
figure
subplot(4,1,1),plot(t(1:length(h_Alpha_RStab_impulse_Clipped),1),h_Alpha_RStab_impulse_Clipped)
title(['Clipped Alpha Discrete Pulse Response (PRESS ENTER TO CONTINUE)']),ylabel(['Alpha (deg)'])
subplot(4,1,2),plot(t(1:length(h_Q_RStab_impulse_Clipped),1),h_Q_RStab_impulse_Clipped)
title(['Clipped Q Discrete Pulse Response']),ylabel(['Q (deg/sec)'])
subplot(4,1,3),plot(t(1:length(h_Nz_RStab_impulse_Clipped),1),h_Nz_RStab_impulse_Clipped)
title(['Clipped Nz Discrete Pulse Response']),ylabel(['Nz (g)'])
subplot(4,1,4),plot(t(1:length(h_Theta_RStab_impulse_Clipped),1),h_Theta_RStab_impulse_Clipped)
title(['Clipped Theta Discrete Pulse Response']),ylabel(['Theta (deg)']),xlabel(['Time (sec)'])
input('');

%%%%% Define sinusoidal sweep signals to be saved in GetData (*.gtd) format

Alpha = [zeros(10,1); h_Alpha_RStab_impulse_Clipped];
Q = [zeros(10,1); h_Q_RStab_impulse_Clipped];
Nz = [zeros(10,1); h_Nz_RStab_impulse_Clipped];
Theta = [zeros(10,1); h_Theta_RStab_impulse_Clipped];
RStab = [zeros(10,1); ones(1,1); zeros(length(h_Alpha_RStab_impulse_Clipped)-1,1)];
Time = (0:1/67:1/67*length(Alpha)-1/67)';
Mach = Mach(1:length(Alpha),1);
Qbar = Qbar(1:length(Alpha),1);
Alt = Alt(1:length(Alpha),1);
Vt = Vt(1:length(Alpha),1);

%%%%% Save sinusoidal sweep signals in *.gtd format

gdsave('G:\projects\Calm_S\f03S01.gtd', Time, Mach, Qbar, Alpha, RStab, Nz, Q, Alt, Vt, Theta)

%%%%% Calculate average fuel weight

Avg_Wf=mean(input_file(:,actual_Wf))

%%%%% Run Masscalc program

!Masscalc
```

MASSCALC

The following FORTRAN code, written by Mr. Chris Nagy of Quartic Engineering Inc., was used to calculate the mass, center of gravity location, and moments and products of inertia of F-16B, USAF S/N 80-0635, for each test pass (Reference 7).

```
PROGRAM MASSCALC
  IMPLICIT NONE
C
* This program computes the weight, center-of-gravity, and inertia's for
* an F16-B model aircraft with a single centerline external tank. The
* fuel sequence, obtained from T.O 1F-16A-1, is as follows:
*   1) Centerline tank
*   2) Wing tanks equally
*   3) Aft and both forward tanks, delta shared equally between
*      aft and forward
*   4) Reservoir tanks
* Data for the various tanks and components were obtained from GD memo
* on F16 mass properties dated August 18th, 1989 and authored by John
* Baker. Data for the individual components are found in the "MP" array
* in this program.
*
  INTEGER*2 I,J
  REAL*4 WEIGHT, XCG, YCG, ZCG, IXX, IYY, IZZ, IXZ, OLD_WT
  REAL*4 FUEL_WT, FUEL_LEFT, DELTA, XCGMAC, DX, DY, DZ
  REAL*4 MP(24,8)

  DATA ((MP(I,J), J=1,8), I=1,24)/
*  wt        sl      b       l       wl      ix          iy       iz      ixz
  - 17113.,  321.5,  0.0,    90.7,   6321.,  55026.5.,   54391.,  214.,   !B/b15/GU(mod)
  - 56.,     244.9,  30.0,   98.0,   0.,     0.,         0.,      0.,     !EPU fuel
  - 13.,     269.7,  9.5,    64.5,   0.,     0.,         0.,      0.,     !oxygen
  - 13.,     315.0,  0.0,    100.0,  0.,     0.,         0.,      0.,     !fuel inert
  - 16.,     128.8,  0.0,    92.3,   0.,     0.,         0.,      0.,     !surv kit
  - 16.,     193.8,  0.0,    94.8,   0.,     0.,         0.,      0.,     !surv kit
  - 190.,    137.7,  0.0,    105.5,  0.,     0.,         0.,      0.,     !pilot(mod)
  - 190.,    202.8,  0.0,    108.1,  0.,     0.,         0.,      0.,     !pilot(mod)
  - 55.,     426.4,  0.0,    90.0,   0.,     0.,         0.,      0.,     !resid fluid
  - 24.,     375.0,  0.0,    80.0,   0.,     0.,         0.,      0.,     !engine oil
  - 740.,    230.9,  0.0,    104.4,  0.,     0.,         0.,      0.,     !F1 fuel
  - 684.,    297.0,  0.0,    101.9,  87.,    8.,         80.,     0.,     !F2 fuel
  - 442.,    326.0,  -25.0,  97.8,   0.,     0.,         0.,      0.,     !LRes fuel
  - 442.,    326.0,  25.0,   97.8,   0.,     0.,         0.,      0.,     !RRes fuel
  - 2313.,   389.5,  0.0,    99.5,   316.,   354.,       459.,    0.,     !Aft fuel
  - 1143.,   350.0,  0.0,    92.0,   1961.,  135.,       2096.,   0.,     !Wing fuel
  - 22.,     370.0,  0.0,    84.6,   0.,     0.,         0.,      0.,     !Line fuel
  - 1950.,   319.6,  0.0,    38.5,   7.,     593.,       612.,    0.,     !300ECL fuel
  - 12.,     290.0,  0.0,    25.6,   0.,     0.,         0.,      0.,     !300ECL unfuel
  - 69.,     366.3,  -182.6, 91.6,   0.,     11.,        11.,     0.,     !L 16S210
  - 69.,     366.3,  182.6,  91.6,   0.,     11.,        11.,     0.,     !R 16S210
  - 172.,    307.2,  0.0,    52.5,   0.,     17.,        17.,     0.,     !Univ pylon
  - 371.,    327.0,  0.0,    38.1,   10.,    139.,       139.,    1.,     !300G tank
  - 24.,     457.0,  35.7,   90.5,   0.,     0.,         0.,      0.,/    !Chaff
```

```
C---Start with Basic Airframe (Fuel-less) Mass Properties
  WEIGHT = MP(1,1)
  XCG  = MP(1,2)
  YCG  = MP(1,3)
  ZCG  = MP(1,4)
  IXX  = MP(1,5)
  IYY  = MP(1,6)
  IZZ  = MP(1,7)
  IXZ  = MP(1,8)
*
C---Compute Fuel Locations and Proportion Component Inertias for Partly-full

C  Fuel Tanks

  WRITE(6,'(1H0, A,$)') 'Enter Fuel Weight - '
  READ(5,'(F10.0)') FUEL_WT

  !Start with fuel in lines and residue in external tank
  FUEL_LEFT = FUEL_WT - MP(17,1) - MP(19,1)

  !Add-In Resevoir Tanks (Items 13,14)
  IF (FUEL_LEFT .LT. MP(13,1)+MP(14,1)) THEN
   MP(11,1) = 0.                          !F1 Tank
   MP(12,1) = 0.                          !F2 Tank
   MP(12,5) = 0.
   MP(12,6) = 0.
   MP(12,7) = 0.
   MP(13,1) = FUEL_LEFT / 2.    !Left Resevoir
   MP(14,1) = FUEL_LEFT / 2.    !Right Resevoir
   MP(15,1) = 0.                          !Aft Tank
   MP(15,5) = 0.
   MP(15,6) = 0.
   MP(15,7) = 0.
   MP(16,1) = 0.                          !Wing Tanks
   MP(16,5) = 0.
   MP(16,6) = 0.
   MP(16,7) = 0.
   MP(18,1) = 0.                          !External Tank
   MP(18,5) = 0.
   MP(18,6) = 0.
   MP(18,7) = 0.
   FUEL_LEFT = 0.0
   GO TO 10
 ELSE
   FUEL_LEFT = FUEL_LEFT - MP(13,1) - MP(14,1)
 ENDIF

 !Add-In Remainder of Aft Tank (Item 15)
 DELTA = MP(15,1) - MP(11,1) - MP(12,1)
 IF (FUEL_LEFT .LT. DELTA) THEN
  MP(11,1) = 0.                                          !F1 Tank
  MP(12,1) = 0.                                          !F2 Tank
  MP(12,5) = 0.
  MP(12,6) = 0.
  MP(12,7) = 0.
```

```
  MP(15,5) = MP(15,5) * FUEL_LEFT / MP(15,1)                  !Aft Tank
  MP(15,6) = MP(15,6) * FUEL_LEFT / MP(15,1)
  MP(15,7) = MP(15,7) * FUEL_LEFT / MP(15,1)
  MP(15,1) = FUEL_LEFT
  MP(16,1) = 0.                                               !Wing Tanks
  MP(16,5) = 0.
  MP(16,6) = 0.
  MP(16,7) = 0.
  MP(18,1) = 0.                                               !External Tank
  MP(18,5) = 0.
  MP(18,6) = 0.
  MP(18,7) = 0.
  FUEL_LEFT = 0.0
  GO TO 10
ELSE
  FUEL_LEFT = FUEL_LEFT - DELTA
ENDIF

!Add-In Balance of Forward and Aft Fuselage Tanks (Items 11,12,15)
IF (FUEL_LEFT .LT. MP(11,1)+MP(12,1)+MP(15,1)-DELTA) THEN
  IF (FUEL_LEFT/2 .LT. MP(12,1)) THEN
   MP(11,1) = 0.                                              !F1 Tank
   MP(12,5) = MP(12,5) * (FUEL_LEFT/2) / MP(12,1)             !F2 Tank
   MP(12,6) = MP(12,6) * (FUEL_LEFT/2) / MP(12,1)
   MP(12,7) = MP(12,7) * (FUEL_LEFT/2) / MP(12,1)
   MP(12,1) = (FUEL_LEFT/2)
  ELSE
   MP(11,1) = (FUEL_LEFT/2) - MP(12,1)                        !F1 Tank
  ENDIF
  MP(15,5) = MP(15,5) * (FUEL_LEFT/2+DELTA) / MP(15,1)        !Aft Tank
  MP(15,6) = MP(15,6) * (FUEL_LEFT/2+DELTA) / MP(15,1)
  MP(15,7) = MP(15,7) * (FUEL_LEFT/2+DELTA) / MP(15,1)
  MP(15,1) = (FUEL_LEFT/2+DELTA)
  MP(16,1) = 0.                                               !Wing Tanks
  MP(16,5) = 0.
  MP(16,6) = 0.
  MP(16,7) = 0.
  MP(18,1) = 0.                                               !External Tank
  MP(18,5) = 0.
  MP(18,6) = 0.
  MP(18,7) = 0.
  FUEL_LEFT = 0.0
  GO TO 10
ELSE
  FUEL_LEFT = FUEL_LEFT - (MP(11,1)+MP(12,1)+MP(15,1)-DELTA)
ENDIF

!Add-In Wing Tanks (Item 16)
IF (FUEL_LEFT .LT. MP(16,1)) THEN
  MP(16,5) = MP(16,5) * FUEL_LEFT / MP(16,1)                  !Wing Tanks
  MP(16,6) = MP(16,6) * FUEL_LEFT / MP(16,1)
  MP(16,7) = MP(16,7) * FUEL_LEFT / MP(16,1)
  MP(16,1) = FUEL_LEFT
  MP(18,1) = 0.                                               !External Tank
  MP(18,5) = 0.
  MP(18,6) = 0.
```

```
    MP(18,7) = 0.
    FUEL_LEFT = 0.0
    GO TO 10
   ELSE
    FUEL_LEFT = FUEL_LEFT - MP(16,1)
   ENDIF

   !Add-In Centerline External Tank (Item 18)
   IF (FUEL_LEFT .LT. MP(18,1)) THEN
    MP(18,5) = MP(18,5) * FUEL_LEFT / MP(18,1)                !External Tank
    MP(18,6) = MP(18,6) * FUEL_LEFT / MP(18,1)
    MP(18,7) = MP(18,7) * FUEL_LEFT / MP(18,1)
    MP(18,1) = FUEL_LEFT
    FUEL_LEFT = 0.0
    GO TO 10
   ENDIF
*
C---Compute Weight and CGs

   !Basic Equipment (Items 2-10)
10 DO I = 2,10
    OLD_WT = WEIGHT
    WEIGHT = WEIGHT + MP(I,1)
    XCG  = (OLD_WT * XCG + MP(I,1) * MP(I,2)) / WEIGHT
    YCG  = (OLD_WT * YCG + MP(I,1) * MP(I,3)) / WEIGHT
    ZCG  = (OLD_WT * ZCG + MP(I,1) * MP(I,4)) / WEIGHT
   ENDDO

   !Fuel Components (Items 11-19)
   DO I = 11,19
    OLD_WT = WEIGHT
    WEIGHT = WEIGHT + MP(I,1)
    XCG  = (OLD_WT * XCG + MP(I,1) * MP(I,2)) / WEIGHT
    YCG  = (OLD_WT * YCG + MP(I,1) * MP(I,3)) / WEIGHT
    ZCG  = (OLD_WT * ZCG + MP(I,1) * MP(I,4)) / WEIGHT
   ENDDO

   !Stores (Empty External Tank, AIM-9 Launchers) (Items 20-24)
   DO I = 20,24
    OLD_WT = WEIGHT
    WEIGHT = WEIGHT + MP(I,1)
    XCG  = (OLD_WT * XCG + MP(I,1) * MP(I,2)) / WEIGHT
    YCG  = (OLD_WT * YCG + MP(I,1) * MP(I,3)) / WEIGHT
    ZCG  = (OLD_WT * ZCG + MP(I,1) * MP(I,4)) / WEIGHT
   ENDDO
*
C---Compute Inertias

   !Basic Equipment (Items 2-10)
   DO I = 2,10
    IXX  = IXX + MP(I,5) + MP(I,1) / 32.17405 *
   -    ((MP(I,3) - YCG)**2 + (MP(I,4) - ZCG)**2) / 144
    IYY  = IYY + MP(I,6) + MP(I,1) / 32.17405 *
   -    ((MP(I,2) - XCG)**2 + (MP(I,4) - ZCG)**2) / 144
    IZZ  = IZZ + MP(I,7) + MP(I,1) / 32.17405 *
   -    ((MP(I,2) - XCG)**2 + (MP(I,3) - YCG)**2) / 144
```

```
       IXZ  = IXZ + MP(I,8) + MP(I,1) / 32.17405 *
     -      ((XCG - MP(I,2)) * (ZCG - MP(I,4))) / 144
      ENDDO

      !Fuel Components (Items 11-19)
      DO I = 11,19
       IXX  = IXX + MP(I,5) + MP(I,1) / 32.17405 *
     -      ((MP(I,3) - YCG)**2 + (MP(I,4) - ZCG)**2) / 144
       IYY  = IYY + MP(I,6) + MP(I,1) / 32.17405 *
     -      ((MP(I,2) - XCG)**2 + (MP(I,4) - ZCG)**2) / 144
       IZZ  = IZZ + MP(I,7) + MP(I,1) / 32.17405 *
     -      ((MP(I,2) - XCG)**2 + (MP(I,3) - YCG)**2) / 144
       IXZ  = IXZ + MP(I,8) + MP(I,1) / 32.17405 *
     -      ((XCG - MP(I,2)) * (ZCG - MP(I,4))) / 144
      ENDDO

      !Add In Effects of Stores (Empty External Tank, AIM-9 Launchers, chaff)
      DO I = 20,24
       IXX  = IXX + MP(I,5) + MP(I,1) / 32.17405 *
     -      ((MP(I,3) - YCG)**2 + (MP(I,4) - ZCG)**2) / 144
       IYY  = IYY + MP(I,6) + MP(I,1) / 32.17405 *
     -      ((MP(I,2) - XCG)**2 + (MP(I,4) - ZCG)**2) / 144
       IZZ  = IZZ + MP(I,7) + MP(I,1) / 32.17405 *
     -      ((MP(I,2) - XCG)**2 + (MP(I,3) - YCG)**2) / 144
       IXZ  = IXZ + MP(I,8) + MP(I,1) / 32.17405 *
     -      ((XCG - MP(I,2)) * (ZCG - MP(I,4))) / 144
      ENDDO
*
C---Compute MAC CG and Delta CGs in Feet
      XCGMAC = (XCG - 273.11) / 135.84 * 100.
      DX = (XCG - 320.65) / 12
      DY = (YCG -  0.) / 12.
      DZ = (ZCG - 91.) / 12
*
C---Output Mass Properties
      WRITE(6,'(1H0, A, 2X, 3(1X,A,3X), 4(2X,A,3X))')
      - 'Weight','X-cg(%MAC)','Y-cg','Z-cg','Ixx','Iyy','Izz','Ixz'
      WRITE(6,'(1H0, F6.0, 2X, F6.2, 1H(, F4.1, 1H),
     -      2(F6.2,2X), 1X, 4(F6.0,2X))')
      - WEIGHT, XCG, XCGMAC, YCG, ZCG, IXX, IYY, IZZ, IXZ
      WRITE(6,'(1H , 8X, 3(F6.2,2X))')
      - DX, DY, DZ
*
      STOP
      END
```

The following two subsections describe in more detail the PCPID program algorithm used to estimate aircraft stability derivatives and the HAVE DERIVATIVES process used to process the pitch sweep responses prior to input into PCPID.

PERSONAL COMPUTER PARAMETER IDENTIFICATION (PCPID)

The PCPID software, which incorporated NASA's parameter estimation (PEST) program (Reference 4), required time histories of an aircraft input, typically a doublet, and the associated aircraft responses. The aircraft responses used for the HAVE DERIVATIVES project were angle of attack, pitch rate, pitch angle and normal acceleration. The PCPID used a set of equations of motion (EOM) to compute expected aircraft responses for the actual recorded doublet input. The actual aircraft responses were compared with the computed responses, and the differences were used to adjust the stability derivatives contained in the EOM model in order to achieve better matches. With the modified set of stability derivatives, new time responses were computed, and the process was repeated. The quality of the matches between the computed aircraft responses and the actual aircraft responses were indicated by cost function values for each of the four responses which decreased as the computed responses matched the actual aircraft responses more precisely. Eventually, the iteration process was stopped when the percentage decrease of the cost function values at each iteration was below a given threshold.

The PCPID parameter estimation process is illustrated in Figure F1 for a typical aircraft input and one of the responses. The same process was simultaneously accomplished for all four aircraft responses. More details concerning PCPID can be found in the *Software Users Manual For Personal Computer Parameter Identification* (Reference 1).

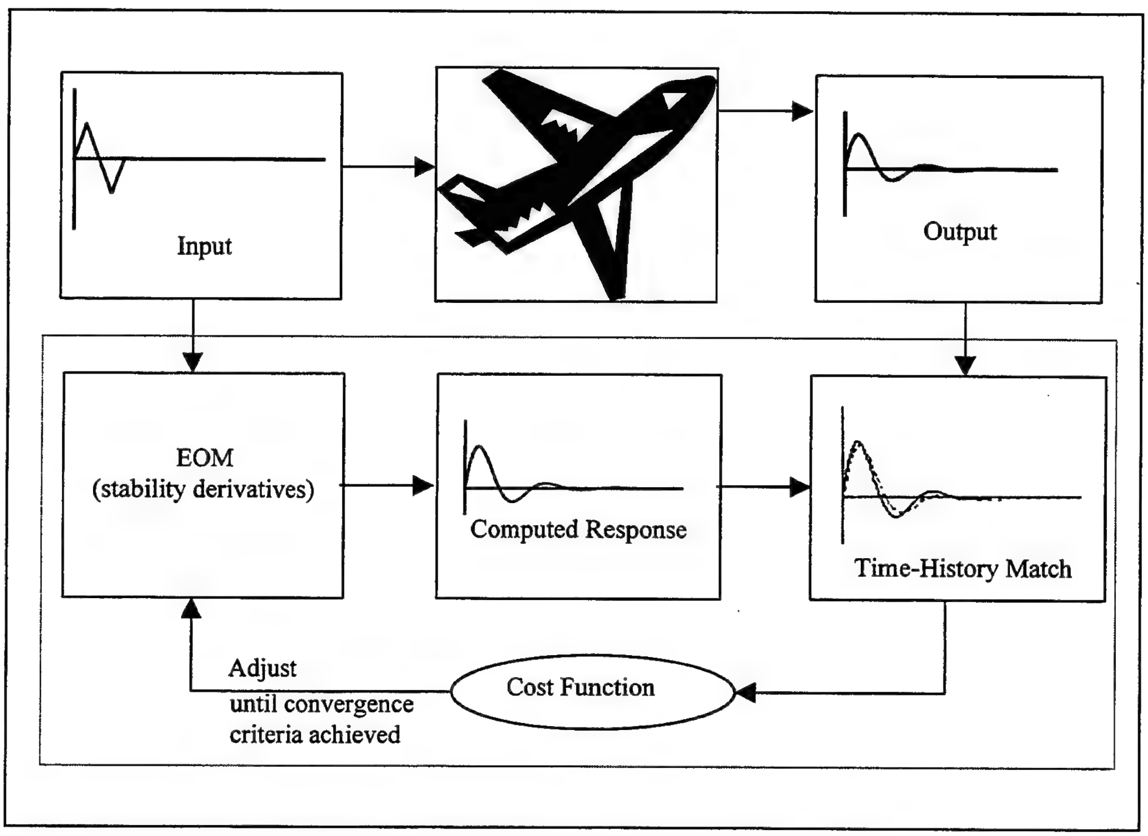

Figure F1 Personal Computer Parameter Identification Algorithm

HAVE DERIVATIVES PROCESS

The HAVE DERIVATIVES process applied an ensemble averaging technique to the data in order to reduce the signal variance before submitting it to PCPID.

The data used at the beginning of the process was the aircraft responses to a pitch sweep. Those responses included angle of attack, pitch rate, pitch angle and normal acceleration. The time histories of the input (typically 60 seconds long) and the aircraft responses to that input were divided into overlapping subdivisions which were transformed into the frequency domain by a fast Fourier transform (FFT). The subdivisions of the input were summed and averaged to form the power spectrum of the input, while the subdivisions of the input and responses were averaged and used to form the cross spectrum of the input and each of the responses. Averaged frequency response functions for each of the response to input combinations were estimated by dividing the appropriate cross spectrum by the power spectrum of the input. An inverse fast Fourier transform (IFFT) was then performed on the averaged frequency response functions to yield the aircraft time domain responses to a unit amplitude discrete pulse input.

The discrete pulse time responses were then entered into the PCPID along with a computer generated unit amplitude discrete pulse function as a simulated input. The PCPID procedure was the same: two time responses were compared, one being the result of the IFFT, the other being the response to a unit amplitude discrete pulse computed with the EOM model and the estimated stability derivatives. The derivatives were refined until the cost function decreased within convergence criteria.

The HAVE DERIVATIVES process illustrates in Figure F2 a typical aircraft response to a frequency sweep input. The process was simultaneously accomplished for all four aircraft responses to the input.

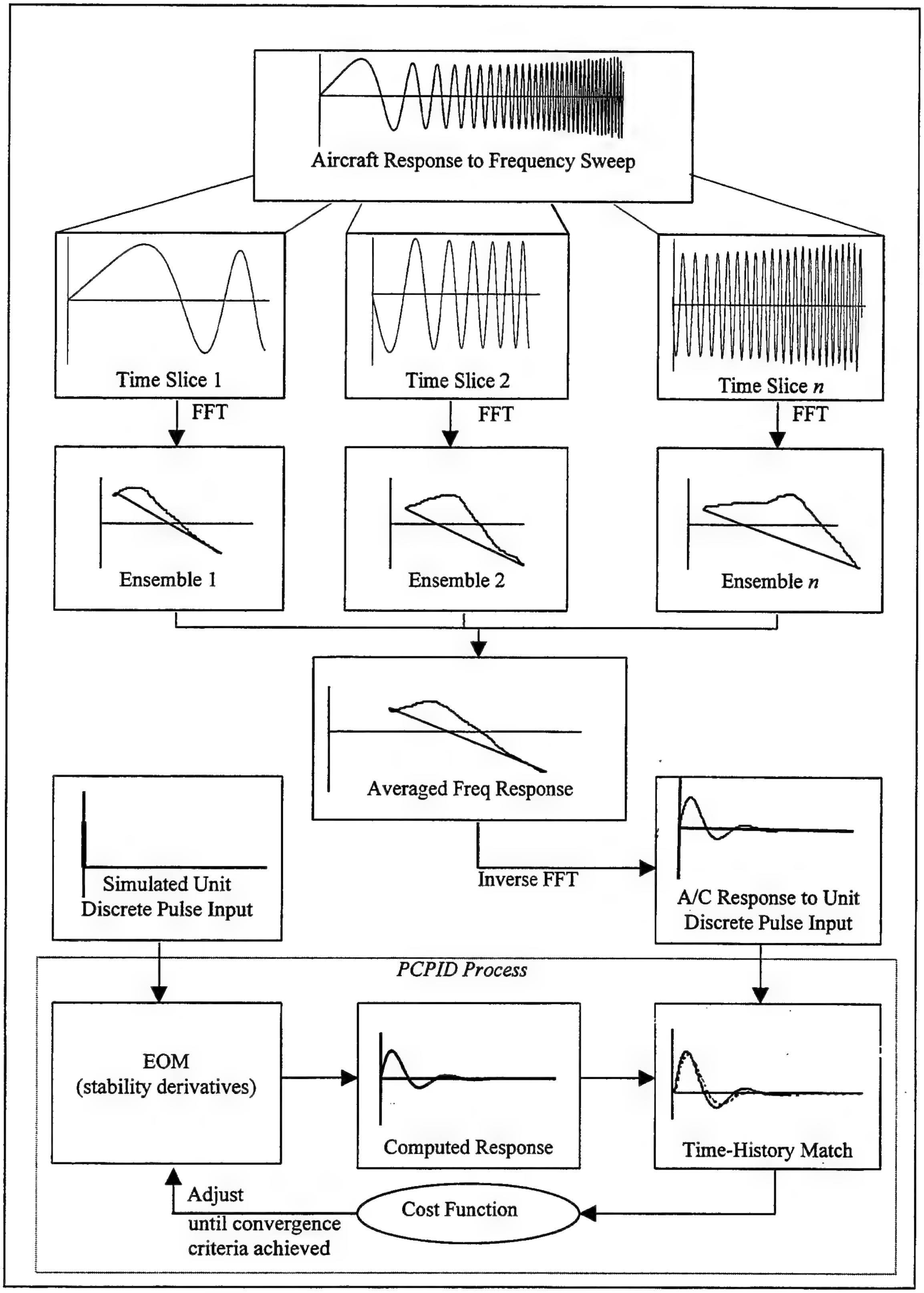

Figure F2 HAVE DERIVATIVES Process with Personal Computer Parameter Identification

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	Definition	Units
AFB	Air Force Base	---
AFFTC	Air Force Flight Test Center	---
AFIT	Air Force Institute of Technology	---
AGL	above ground level	---
AOA	angle of attack	degree
ASCII	American Standard Code for Information Interchange	---
ATIS	airborne test instrumentation system	---
CI	confidence interval	---
CR	Cramer-Rao	---
$C_{N\alpha}$	$\partial CN/\partial\alpha$	per degree
$C_{N\delta e}$	$\partial CN/\partial\delta e$	per degree
$C_{m\alpha}$	$\partial Cm/\partial\alpha$	per degree
$C_{m\delta e}$	$\partial Cm/\partial\delta e$	per degree
C_{mq}	$\partial Cm/\partial q$	per radian
cg	center of gravity	feet
DAS	data acquisition system	---
EOM	equations of motion	---
FFT	fast Fourier transform	---
g	acceleration due to gravity	g
HUD	head-up display	---
Hz	hertz	---
IFFT	inverse fast Fourier transform	---
LCB	lower confidence bound	---
M	Mach number	---
NASA	National Aeronautics and Space Administration	---
NATO	North Atlantic Treaty Organization	---
N/D	nondimensional	---
n_z	normal acceleration	g
PA	pressure altitude	---
PCPID	Personal Computer Parameter Identification	---
PEST	parameter estimation	---
q	pitch rate	degrees per second

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Concluded)

Abbreviation	Definition	Units
TLR	technical letter report	---
TPS	Test Pilot School	---
UCB	upper confidence bound	---
USAF	United States Air Force	---
YAPS	yaw angle of attack Pitot static	---
Δ	increment of change	---
α	angle of attack	---
θ	pitch angle	---

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